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ECON INCORPORATED

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AN ASSESSMENT OF THE BENEFITS OF THE USE OF NASA DEVELOPED FUEL CONSERVATIVE TECHNOLOGY IN THE U.S. COMMERCIAL AIRCRAFT FLEET

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NOTE OF TRANSMITTAL

In a brief but intensive study we have investigated the benefits that will accrue from the application of NASA sponsored fuel conservative technology developments in the U.S. commercial aircraft fleet.

Models which forecast as a function of time the demand for commercial passenger air transportation (revenue passenger miles) and the composition of the aircraft fleet to supply the transportation, have been developed and applied to estimate the fuel savings that result from the proposed program.

The gallons of fuel saved and the net economic benefits produced by the fuel savings are both quantified.

Principal Investigators for this study were Dr. P. Ginsberg and Dr. P.M. Lion. Dr. A.L. Kornhauser performed the analysis of the technology combinations, and Dr. R. Fish assisted in the collection of the data base and the evaluation of the results.

We wish to express our gratitude to Dr. J. Klineberg and Mr. L. Williams of NASA for their assistance in the formulation of the problem and in obtaining certain of the key data needed to perform the study.

Project Manager:

B. P. Miller

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1.0 SUMMARY

This report estimates costs and benefits of a Fuel Conservative Aircraft Technology Program proposed by NASA. The proposed program has six separate technology elements defined by NASA:

(a) Engine Component Improvement

(b) Composite Structures

(c) Turboprops

(d) Laminar Flow Control

(e) Fuel Conservative Engine

(f) Fuel Conservative Transport

There are two levels: the baseline program is estimated to cost $490 million over 10 years with peak funding in 1980. The Level II Program is estimated to cost an additional $180 million also over 10 years. Peak funding for the entire program occurs in 1979. Emphasis throughout the program is on implementation of the research in operational aircraft at the earliest possible date. Therefore, items such as maintainability and reliability receive high priority.

Discussions with NASA and with representatives of the major commercial airframe manufacturers were held to estimate the combinations of the technology elements most likely to be implemented, the potential fuel savings from each combination, and reasonable dates for incorporation of these new aircraft

into the fleet. The consensus of these discussions was that, with the NASA program, four fuel conservative aircraft are likely to be introduced before 2000: a short range aircraft in 1987 with 35% fuel savings, a derivative of this model in 1995 with 45% fuel savings, a medium range aircraft in 1990 with 45% fuel savings, and a long range aircraft in 1995 with 45% fuel savings. The short range aircraft would be turbo-props with composite materials used for the wing and tail. They would have an improved engine core and several aerodynamic improvements. The medium range aircraft would also be a turbo-prop and would be an all composite structure; it would also incorporate improvements in engine technology and aerodynamic improvements. The long range aircraft would be made of composite materials, would use laminar flow control, and would have a new fuel conservative engine. All four would have active controls.

To estimate the fuel savings for these aircraft, demand for domestic air travel (revenue passenger-miles) was projected through 2005. From an analysis of trends in GNP and yield (average price of air transportation) a growth rate of about 4.2% over this period was estimated. The market for new aircraft was estimated using a fleet inventory model. Key assumptions of an aircraft lifetime of 15 years and load factors of 55% are discussed, and the sensitivity of the results to these parameters is calculated.

Two scenarios were run using these models. The first assumes that the NASA research program is not undertaken and that several evolutionary fuel conservative changes, based on existing technology, are incorporated into derivative aircraft in the early 1980's. Improvement in specific fuel consumption would be about 10%. The second scenario assumes the NASA research program is undertaken and introduces both the derivative aircraft and the new aircraft described above. Fuel savings attributable to the NASA Program are the difference between the two scenarios analyzed.

Results for the baseline case (4.2% growth rate) are 90.3 billion gallons of fuel (or approximately 2.15 billion barrels)* will be saved for domestic and U.S. international air operations over the 30 year period (1976-2005). These results are shown in Figure 1.1. This is about 21% of the total that would otherwise be used. To put this figure in perspective, the entire United States consumes about 17 million barrels of petroleum products daily for all uses (1974). On an annual basis in 2005, the savings are 9.1 billion gallons per year or about 40% of the fuel that would otherwise be consumed by the U.S. domestic and international commercial aircraft fleet. The figure cited is on the conservative side, since the assumed growth rate (4.2%) is lower than many estimates. The savings grow exponentially with increasing growth rates.

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*1 barrel = 42 gallons (jet fuel)

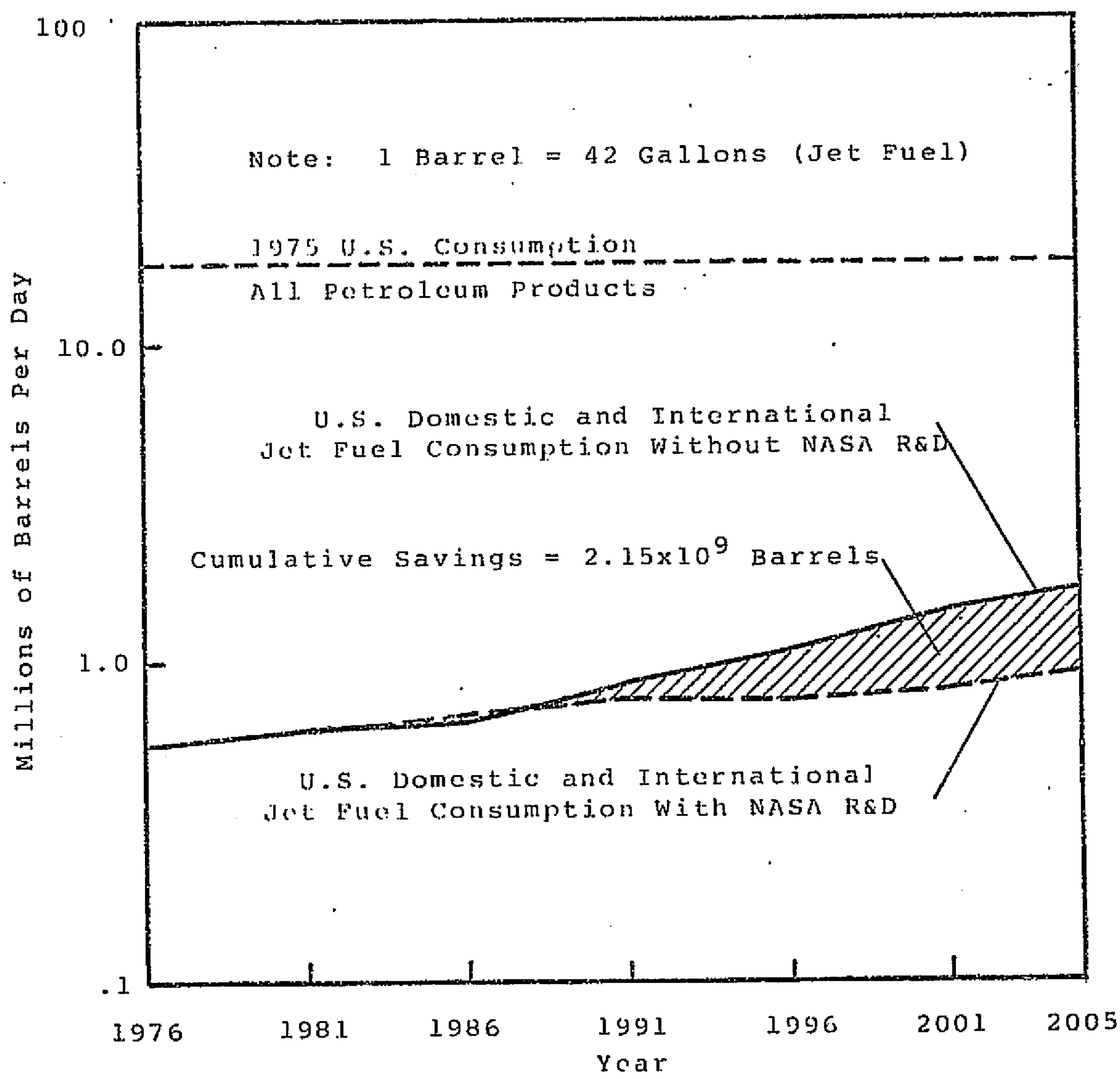

Figure 1.1 Fuel Used by the U.S. Domestic and International Airtransport Fleet

The sensitivity of these results to changes in the parameters was calculated. For example, delay of the entire program for one year reduces fuel savings by about 8 billion cumulatively. On the other hand, acceleration of the entire program by one year increases savings by about the same amount. A shortfall of 5% in achieving the target R&D objectives of reducing specific fuel consumption reduces fuel savings by about 9.5 billion gallons (10%) cumulatively. If the target objectives are surpassed by 5% an additional savings of about 9.5 billion gallons will be obtained. Increasing load factor to 60% decreases fuel savings by about 7.5 billion gallons but the percentage savings remain almost the same. Increasing aircraft lifetime to 20 years reduces fuel savings by about 12.5 billion gallons. However, fuel consumption without the NASA program is higher and, therefore, the savings become relatively more important.

To compare the savings in fuel requirements in the late 1980's and the 1990's to the program costs from 1976 to 1985, discount rates of 10% and 5% were used. In the most conservative case U.S. jet fuel prices were assumed to remain constant at 22 cents per gallon; the present value of the savings then is $2.7 billion ($ 1975) at a 10% discount rate, compared to a present value of the NASA R&D program costs of $425 million ($ 1975). The payback date is 1990. With a discount rate of 5% the present value of the savings is $6.4 billion ($ 1975) and the payback date is 1989.

Alternatively, if fuel costs escalate at a rate of 7% a year, then the present value of the savings is $11.7 billion ($ 1975) at a 10% discount rate. The payback date is 1987. With a discount rate of 5% and an escalation of fuel costs of 2%, the present value of the savings is $14.4 billion ($ 1975). The payback date remains 1987.

In summary, within the broad range of alternatives considered the Fuel Conservative Aircraft Technology Program proposed by NASA promises substantial returns to U.S. society under very conservative assessment criteria.

2.0 INTRODUCTION

Since the Arab oil embargo in 1973 and the effective cartelization of OPEC oil prices in 1974, the United States government has encouraged serious fuel conservation measures and efforts to reduce dependence upon foreign sources of energy. In response to these national objectives, NASA, in collaboration with industry, is proposing a research and development program to demonstrate the technology necessary for a new generation of fuel efficient commercial transports.

There exists a 10-to 15-year research and development lead time preceding operational certification for commercial transports. Aircraft in the present fleet were conceived, designed, and produced to balance fuel, maintenance, capital, and labor costs based on design cost parameters that are no longer applicable. In particular, aircraft operating economics have been based on jet fuel prices of 9¢ to 12¢ a gallon. Fuel prices had remained in that range for 20 years prior to 1974. In 1974, however, airline fuel contracts were negotiated reflecting 100% domestic fuel price increases. For U.S. international flights, price increases were 200%.

The purpose of this investigation is to assess the fuel savings and economic benefits that may evolve from the proposed NASA research and development program. The assessment will be conducted by evaluating the streams of expected benefits and

expected costs (not including industry expenditures) from NASA supported efforts. Since physical shortages of petroleum products have resulted in government intervention in resource allocation mechanisms using complicated allocation formulas, net dollar estimates of benefit streams may not suffice due to the unpredictability of "market prices." Therefore, benefits will be measured in both dollar values and in terms of total domestic fuel saved in satisfying the demands for air transportation by United States carriers.

The process of commercial aircraft development is both continuous and incremental. In a given time period, both derivatives of current production aircraft and entirely new designs may be introduced. The need to examine both derivative models and the new generation of aircraft incorporating the proposed research and development program implies a planning cycle of 30 years, i.e., to the year 2005. A 30-year planning horizon limits the usefulness and feasibility of methodologies based upon network or city-pair traffic demands and financial flow analyses of individual airlines. While these "bottom up" approaches (which require large data bases) are necessary for short term planning, in this case, it is necessary to concentrate on aggregate analysis of the entire industry. Therefore, such problems as apparent overcapacity at some points, or whether one airframe manufacturer or a particular airline could finance the development and acquisition of new aircraft, will not be addressed. The "top down" approach compares the aircraft fleet that would be in existence without the NASA

R&D program with the fleet which results assuming the NASA program is undertaken and the technology is transferred and incorporated into derivative and new generation aircraft.

In order to isolate the interaction between supply and demand factors, the assessment of benefits and costs is made for a given demand structure that is invariant to the NASA research and development program. This approach eliminates the double counting of benefits.

The history of technology transfer to the commercial transport fleet has been characterized by the joint application of military and private sector developments.* However, since fuel conservation is not a principal mission of the military, it can be expected that the development costs shared in the past by the U.S. government through military funding will have to come from other sources. Therefore, a gap exists in the support levels which have historically been available for research and development in this area. This gap can be filled by NASA participation. Without NASA participation, profitability and stockholder preferences of individual firms will be the primary criteria for development efforts. These criteria will not necessarily lead to the same emphasis on fuel conservation, especially where uncertain or divergent views with respect to future pricing and availability of fuel are held.

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*Working Group Reports, AIAA Workshop Conference, December 2-4, 1974; The Role of Technology in Commercial Aircraft Policy Formulation, AIAA, March 21, 1975. p. 34.

ECON, Inc. has examined the NASA R&D proposals and has, with NASA's cooperation, visited Lockheed, McDonnell-Douglas, and the Boeing advanced development departments. The purpose of these visits was to help assess the feasibility and timing of combinations of technology programs. The technology programs identified represent best judgements for a static analysis of potential fuel savings. Ongoing economic assessments of a NASA program need to be undertaken in order to incorporate evolving achievements that feed back into the R&D allocation process. Explicit breakthroughs in technology which are economically reasonable are difficult to predict. However, if success is demonstrated in one area, funds can be transferred from another area to exploit the technology breakthrough.

3.0 PROJECTIONS OF AIR TRAVEL DEMAND

3.1 Industry Outlook

While much research is being conducted on alternate forms of energy, the U.S. and world airline industries will rely on petroleum fuels for the forseeable future. It is our assessment that hydrogen-fueled and nuclear-powered airplanes will not be incorporated into the fleet until after the year 2000. Using historical life-cycle relationships for subsonic aircraft, two generations of petroleum-fueled aircraft can be expected in this period; namely "derivative" models which will become operational in the mid-1990's. The economics of airline finances and operations will determine the dates of introduction of both generations. This implies that new aircraft will be put into service to satisfy the demand for air travel.

NASA's proposed R&D program can substantially alter the kind of aircraft and, hence, the level of fuel efficiency that the manufacturers will offer the airlines.

3.1.1 Fuels

As shown in a recent survey the fuel problem has become the number one problem of the airlines.* (See Table 3.1.)

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*Conducted by L. Williams of NASA Ames Research Center at the "Transportation Demand and Systems Analysis Conference," June 2-4, 1975 Washington, D.C.

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Table 3.1 Air Transportation Problem Priorities
Average Response (1=Highest, 6-Lowest)

Affiliation	Number of Responses	Emissions	Noise	Airport Congestion	Ground Access	Fuel Cost	Other Costs
Airline	12	5.3	4.4	3.3	3.6	2.3	2.6
Manufacturer	8	5.1	3.5	3.4	2.8	3.0	3.3
University	9	4.9	3.7	3.4	2.1	2.9	3.4
Government	8	4.5	2.9	3.5	2.9	3.3	4.0
Other	5	4.0	5.4	4.2	4.0	1.8	3.2
All	42	4.9	3.9	3.5	3.0	2.7	3.2
Ranking		6	5	4	2	1	3

Moreover, forecasts by the air transportation industry of future fuel prices over the next decade indicate increases as high as 320% of present price levels. For purposes of this evaluation, it is assumed that 1980 domestic fuel prices will reach the level of present international fuel prices (35 cents/gallon) and, thereafter, will follow the general trend in consumer prices. In preliminary analysis for Project Independence it has been estimated that the U.S. domestic supply in 1985 could be 15 million barrels/day.* Based on 1974 usage allocations,** this implies less than 1 million bbl/day of jet fuels available for military, private and airline industry use. This represents 6% of total petroleum consumption. If, then, only 900,000 bbl/day are available in 1985, the demand for air travel may exceed available supply. This constraint, if effective, would imply a greater degree of regulation of air fares and a deterioration in the availability of service.

3.2 Demand for U.S. Domestic Air Travel

While domestic air travel, measured by revenue passenger miles, has grown an average of 11.0% over the last 13 years, industry, private and government forecasts predict

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*Project Independence Report, Federal Energy Administration, November 1974, p. 81 (at $11 per barrel under business as usual assumptions).

**"980,000 bbl/day of jet fuel demand out of 16,960,000 bbl/day of total demand." The Oil and Gas Journal, January 27, 1975, p. 104.

growth to fall within the range of 4.0% to 8.0% for the 1975 to 1990 period. This fall-off in growth can mainly be described by the term "maturing industry." After examination of these forecasts, quantitative explanations have been difficult to obtain. Our forecast of the demand for air travel uses two explanatory or independent variables: real income and the price per mile of air travel (yield). The historical period used to generate parameters from which our conditional forecasts are made is 1962 through 1974, the period associated with commercial jet transports. Real income and real price were used to explain revenue passenger mile demand assuming a linear relationship. During the period 1962-1974, GNP (deflated by the consumer price index) increased at an average annual rate of 3.6% and yield (deflated by the consumer price index) decreased at an average annual rate of -2.8%. During the 1960's and early 1970's airline travel was a "good buy." For the forecast, it is assumed that deflated GNP will grow at an average annual rate of 3.0% and that yield will decrease at an annual rate of -1.0% over the thirty year planning period.

The GNP forecast is, of course, uncertain. The yield assumptions are supported by the implementation of the one-stop charter, resulting in average load factors which will not fall below 55%, and more productive aircraft in the fleet. The continual decrease in yields (-1.0% growth) applies both with and without the NASA R&D program. This will hold even if the

decrease in direct operating costs resulting from the incorporation of fuel conservative technology will be offset by higher capital costs. It should be pointed out that the -1% forecast in yield growth is only 35% of the average decrease of the past thirteen years. Moreover, CAB regulation and route structuring provide support for the assumption of a real decrease in yield. While at first this appears to be an optimistic assumption about the future long run cost of air travel, the derived forecasted demand for air travel is still conservative. The average annual compound growth rate of revenue passenger miles is forecasted to be 4.2% to the year 2005. Since the demand estimate is conservative, net benefits accruing to the NASA R&D program will also be conservative. In order to test the robustness of the benefit estimates, growth rates between 3% and 8% were incorporated into the analysis. The forecasted demand envelope is assumed to be invariant to the NASA R&D program. That is, while NASA technology efforts increase fuel efficiency and give impetus to reduced fares through reduced direct operating costs, it is assumed that increased capital costs for the new technology will offset these implied decreases in direct operating costs. While valid for a "first order" estimate this assumption needs further investigation during an ongoing assessment program.

3.3 U.S. International Demand for Air Travel

In 1974 international revenue passenger miles were

33.2 billion or approximately 25% of domestic travel. Since changes in the international exchange rate have large effects on total trip costs, conditional forecasts on exchange rates would add another dimension to the forecasting problem. Moreover, while our analysis shows that international travel is more sensitive to income changes and less sensitive to price changes than is domestic travel, the incorporation of exchange rate movements would likely cancel out any differences in income and price sensitivities. Therefore, it is assumed that the 1974 relationship of international revenue passenger miles (RPM's) by U.S. carriers will remain a constant 25% of domestic RPM's in the future, and that aircraft fleets for international travel (along with fuel consumption) can be estimated from the U.S. domestic forecasts.

3.4 Foreign Demand for Aircraft

Foreign demand for aircraft has a positive impact on the U.S. balance of payments and presently the great majority of the sales backlog of airframe manufacturers is for foreign delivery.* The world jet aircraft fleet (excluding the USSR) numbers approximately 4500. About 50% are U.S. owned and 50%

*301 out of 465 aircraft as of January 1, 1975, U.S. and International Commercial Jet Transport Fleets, February 15, 1975, Marketing Department, Pratt and Whitney Aircraft.

owned by the rest of the world. While foreign travel (non-U.S. airports) has no direct impact on U.S. fuel conservation, the aircraft and engine manufacturers take into account total world sales in deciding whether to commit to a development effort. With higher international fuel prices, the NASA R&D effort will likely provide additional benefit in the form of an incentive for the purchase of U.S. built fuel conservative aircraft by the airlines of other nations. In estimating the effect on balance of payments, it is assumed that the ratio between U.S. and foreign fleets is maintained for the period under consideration, and that for every aircraft sold to a U.S. airline, one aircraft is purchased by a foreign (non-U.S.) airline.*

*This assumption has been corroborated by industry spokesmen.

4.0 FUEL CONSERVATION TECHNOLOGY PROGRAM

NASA's proposed fuel conservation technology program is a result of the combined efforts of scientists, engineers and managers from NASA (Ames, Langley, Lewis, and Flight Research Centers), airframe industry (Boeing, McDonnell-Douglas, Lockheed), engine manufacturers (Allison, General Electric, Pratt & Whitney, Hamilton Standard) and air carriers (United, Delta, Eastern, TWA). Additionally, NASA has convened an Advisory Board consisting of representatives of academia and the concerned industries to review the proposed program. The purpose of the program is to provide technological advancement opportunities that will result in conservation of fuel in air transport, with a goal of developing and demonstrating the technology for implementation in new generations of fuel-efficient aircraft.

Six major programs have been defined. Included are three programs that focus on the implementation of evolutionary improvements in aerodynamics and propulsion. The remaining three programs, composite primary structures, turboprops and laminar flow control, represent efforts to develop technologies that may result in large fuel savings even though they are radically different from those currently used in civil air transports.

In several cases two levels of activity were defined by NASA for each technology element. Those activities judged

to be of first priority were grouped in what is called the baseline program. In some cases, additional work judged to be important but of lower priority was also defined and designated as the Level II program.

In meetings with the hardware manufacturers it was emphasized that from a theoretical standpoint there is no doubt that each technology program could indeed lead to fuel conservation; the real challenge is to develop the technologies to a point where they can be incorporated in production aircraft and result in a more economic air transport system at the earliest possible date.

4.1 Elements of the Technology Program

4.1.1 Engine Component Improvement

This effort is directed at developing improved engine components that could be used in new production of existing engine types and in newly designed engines. The focus of the program is aimed at producing an engine that will not suffer a large degradation of performance while in service as well as the development of fuel-efficient components. Elements of the program include the development of wear resistant blade shapes, active clearance controls, mixers and compliant seals. The proposed activity includes tests of in-service engines in order to determine the causes of engine performance degradation with time. These improved components are expected to be ready for

use on engines produced after 1980. It is estimated that successful development could lead to a 5% decrease in engine specific fuel consumption, relative to the specific fuel consumption of present-generation high bypass ratio engines.

Proposed funding for the engine component improvement program through 1980 totals $40 million of which $15 million is designated for component tests and $25 million for engine tests.

The aircraft manufacturers strongly support this program and believe that the 5% fuel savings is achievable within the proposed funding and time frame. Probability of success for this program is considered to be extremely high.

4.1.2 Fuel-Conservative Engine

This propulsion activity is directed at providing the technology base for achieving higher thermodynamic efficiencies in future engine designs. The program includes a rigorous component development program exploring the design of fans, compressors, combustors, turbines, seals and bearings as well as investigation of unconventional propulsion concepts including regenerators.

Funding totaling $115 million would be provided for improved components to be proved out in a experimental engine program by one contractor. An additional amount of $60 million could support a second contractor in a parallel effort. This

funding would result in the technology readiness of future engines by the first half of the 1980's (1982). Engines using this technology could be expected to be ready for use in new aircraft introduced into service by the late 1980's (1988) and would result in a 10-15% reduction in specific fuel consumption, relative to the specific fuel consumption of present-generation high bypass ratio engines.

While enthusiastic in its support of NASA's continued research in fuel-conservative engine components and a little less supportive of the possibilities of the potential fuel savings, the airframe manufacturers were cautious about their support of the realistic implementation potential of the program. They warned of the potential increased maintenance burden on the airlines that could result in the (small) probability that direct operating costs may increase. They stressed that ease-of-maintenance should be held as a major goal of the NASA program in this area.

Probability of implementation of this technology is relatively lower than for some of the other programs because of the maintenance question.

4.1.3 Composite Primary Aircraft Structures

The use of composite materials in the primary structural components of aircraft offers the potential of substantial vehicle weight savings. These weight savings translate into fuel savings of the order of 10-12% as compared to all-metal aircraft.

Extensive service experience is required in order to enable the airframe industry to commit to the extensive use of composite primary structures in new transport aircraft. The NASA program is structured to minimize the risk to the airframe manufacturers in the implementation of composite structure technology in new transport aircraft. The previously planned NASA program called for service testing of a composite vertical tail and wing. The fuel conservative program includes (1) expansion of the vertical tail flight testing program to include three major airframe manufacturers, (2) extension of the vertical tail programs to support the early production phase, and (3) construction and service life testing of a composite fuselage section. The previously planned NASA program (vertical tail and wing) and items (1) and (2) are included in the baseline program. Item (3) is added in the Level II program.

Proposed baseline funding for work on composites totals $110 million through 1982 with an additional $70 million allocated to Phase II that is also to terminate in 1982.

Significant aspects of the composite program will be available as early as 1982 for incorportion into the production of derivative aircraft and are expected to yield 6% improvement in fuel efficiency. Complete benefits of the composite structure yielding fuel savings of up to 12% can be incorporated in production aircraft beginning in 1990.

Probability of implementation of this program in production aircraft is very high because (1) its definite weight savings, (2) its potential to also reduce production costs in the manufacture of aircraft and (3) the emphasis of this program on flight testing and implementation.

4.1.4 Aerodynamics (Fuel-Conservative Transport)

This activity is directed at the evolutionary improvement of aerodynamic design and the development of active controls technology. NASA will continue to work closely with the manufacturing industry to develop the aerodynamics technology base for the design of fuel-conservative aircraft. Higher aspect-ratio wings with lower sweep and improved airfoil sections will be designed based on improved numerical methods and the results of extensive wind tunnel tests. Critical problems of active controls to permit designs with reduced static stability margins will be addressed. Present ongoing efforts will be intensified. It appears that specific fuel consumption savings on the order of 10-20% are possible. How much of this can be attributed to a more vigorous NASA program is not clear. The airframe industry has had, in the last four decades, a NASA (previously NACA) program from which to draw technological expertise and its members strongly urge a continuance of this source of improved technology. Strict allocation of benefits between NASA and industry is irrelevant. What is more

important is that joint efforts of NASA and industry can produce the technological base for more fuel-conservative aerodynamic designs. These technologies will be ready for application to new designs in the early 1980's. It is possible that some aerodynamic changes could be incorporated in the design of derivatives of currently produced aircraft.

Industry places potential fuel savings from active controls at 5% with an additional 10% savings available from better wing body integration and use of a super critical wing having a refined airfoil shape, increased thickness, greater span, higher aspect-ratio, higher design lift and reduced sweepback.

Proposed funding for this activity totals $50 million through 1982 of which $25 million is for flight tests, $10 million for aircraft design and wind tunnel tests and $15 million for component development.

The airframe representatives indicated very strong agreement with the objectives, timetable and funding for this program. Probability of implementation of this program is very high. The degree of implementation is dependent on how strongly the design objectives of the airframe manufacturers shift toward fuel conservation.

4.1.5 Turboprops

Preliminary performance calculations indicate that fuel savings on the order of 15% may be associated with the

high propulsive efficiency of propellers over turbofans having an equivalent level of core engine technology. An additional 5% saving can be gained from improvements over current core engine technology. Many questions are unanswered with regard to the performance of propeller-driven aircraft at speeds and altitudes approaching those of current jet transprops. These questions will be addressed in preliminary phases of a program aimed at demonstration of a reliable turboprop propulsion system. Work through an engine demonstration phase represents the baseline program. Included are investigations of propeller aerodynamics and structure/propeller/airframe integration, configuration, and gears and controls as well as ground tests. A flight demonstration using a transport aircraft is included in the Level II program.

Level I funding totals $75 million through 1982 and will determine the viability of the turboprop propulsion concept for a high-altitude high-(subsonic) Mach-number passenger transport. Positive results in the baseline program may lead to a Level II flight demonstration requiring $50 million for a four-year program ending in 1984.

The enthusiasm for the turboprop concept by the representatives of the airframe manufacturers came as somewhat of a surprise. The problems of vibration, noise and possible speed restrictions were brought out; nevertheless, the encouragement came for the high potential fuel conservation.

Encouragement was given for accelerating the program if it is felt that the previously mentioned technical problems could be solved.

Under an accelerated program it is possible that a turboprop powered aircraft in the short range category could be developed for the short range market that will begin to develop in 1985. While interest is high in turboprops, the probability of implementation is still rather low, mainly as a result of concern over the question of airline and passenger acceptance of propeller aircraft.

4.1.6 Laminar Flow Control

One of the technology elements with the greatest potential for fuel savings is drag reduction by laminar flow control. The concept is to remove the surface boundary layers by suction in order to maintain laminar flow and the low drag associated with such flow. Potential fuel savings range from a low of 20% to a high of 40%. This has been a tantalizing research area for some time. Previous efforts by the Air Force and Northrop on the X-21 research aircraft did demonstrate the possibility of flow laminarization but did not answer the open questions concerning structural concepts, pumping systems, maintainability and reliability. Recent progress in materials and structures have encouraged NASA to propose a $100 million activity in laminar flow control through 1985. The activity ranges from the study of aircraft concepts and aerodynamics to

flight tests and in-service validation. However, the development risk is substantial. It appears to be a most appropriate government R&D investment because although the potential public benefit is great, the risk of failure is too high to justify investment by the manufacturing industry, particularly in the current economic environment.

The response of airframe manufacturers was unified in emphasizing that if you laminarize the boundary layer you reduce drag and improve fuel efficiency but that this must be done in a manner that must not be overwhelmed by increased capital cost and/or increased maintenance costs. One manufacturer suggested that almost half of the fuel savings could be gained from aerodynamic design of a laminar flow wing without suction.

If laminar flow control is to become available, it seems unlikely before 1990. Even then the probability of implementation is lowest of any of the technology programs proposed primarily because of the potentially difficult maintenance problem.

4.2 Likely Combinations of Technology in Operational Aircraft

While hundreds of possible combinations of the above technology activities exist, most of them are non-compatible. For example, a fuel-conservative engine and turboprop in conjunction with laminar flow control appear to be an unlikely combination of technologies to be implemented on the same air-

craft. Other combinations lead to at best a multiplicative (percent of a reduced base) savings rather than a straight summation of fuel saving percentages.

The introduction date of derivative and new aircraft that incorporate fuel conservative market-ready technology is dependent on both the availability of the technology and the market for such aircraft type in the airline industry.

Assuming various levels of success of the NASA program yields a tree of possible implementation scenarios as depicted in Figure 4.1. Branches of the tree are formed at times of revaluation of the program. The major branch points will occur at time of the following decisions:

- go or no-go with turboprops
- go or no-go with the development of a production fuel-conservative engine
- go or no-go with implementation of LFC
- possible federal policy directives on short range air travel.

Numerous nodes are also depicted on the fuel-conservative transport scenario tree. Each node represents a potential derivative or new fuel-conservative aircraft. Listed for each node are (a) the most likely time for introduction into revenue producing service of a fuel-conservative transport that includes the sum of the technologies listed on each upstream node,

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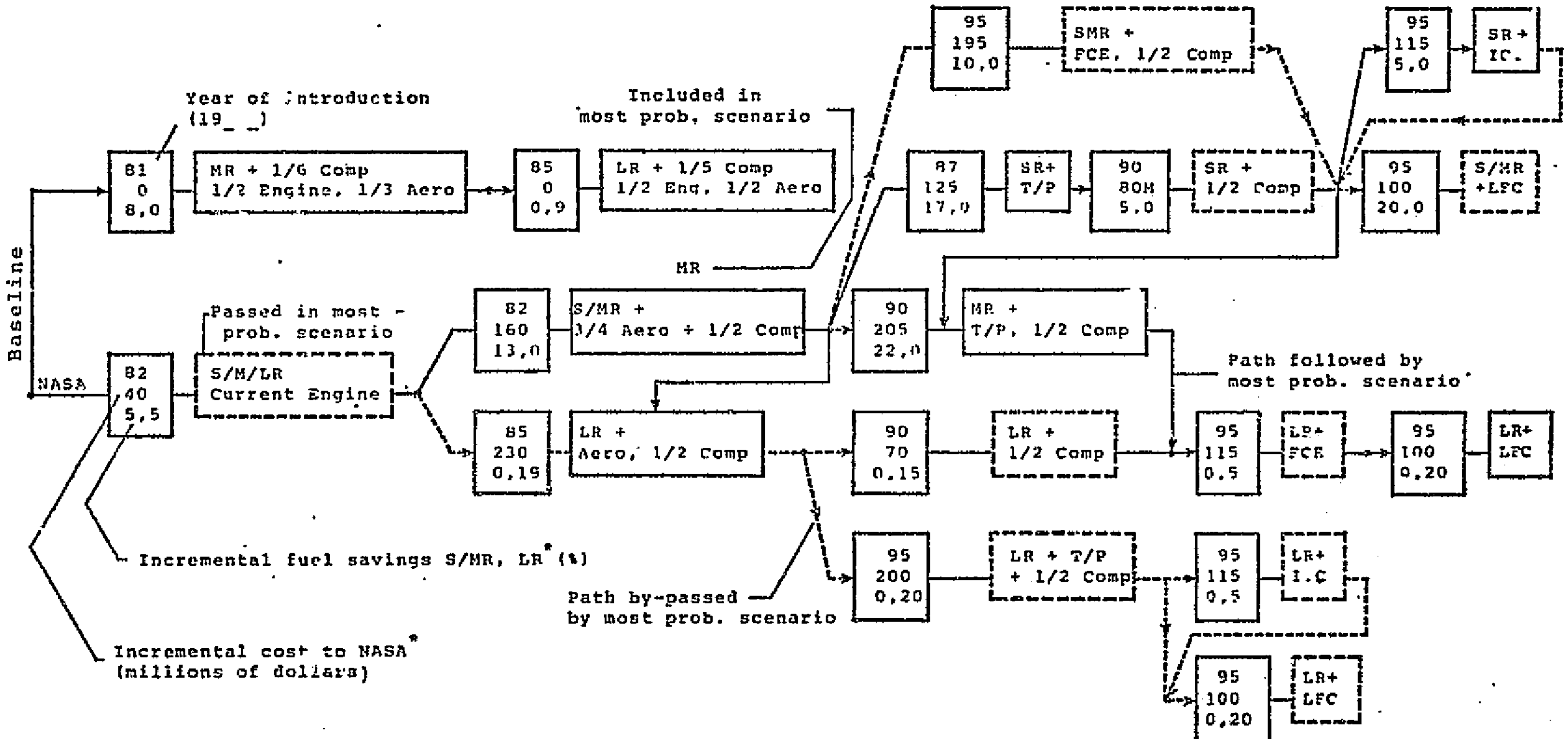

Key

Aero: Aerodynamics and Active Controls (Fuel Conservative Transport)
Comp: Composite Structure, Wing, Tail & Fuselage
FCE : Fuel Conservative Engine
IC : Improved Engine Core
LFC : Laminar Flow Control
LR : Long Range Aircraft
S/MR: Short to Medium Range Aircraft
T/P : Turboprop
1/3, 3/4 Aero: Partial Use of Active Controls and Drag Clean-Up
1/5, 1/6 Comp: Composite Use in Secondary Structure
1/2 Comp: Composite Structure, Wing & Tail Only
1/2 Eng : Engine Mods

——— most probable scenario
- - - - other possible combinations

*Totals are simple sums of downstream elements.

Figure 4.1 Fuel Conservative Aircraft Scenarios

(b) the incremental cost of the NASA program to develop the incremental technology denoted on the node and (c) the expected incremental savings in fuel consumption.

From this tree a most likely scenario for the introduction of derivative and new aircraft in all three range categories was selected.

4.2.1 Baseline Scenario - The Fleet Without a NASA R&D Program

Given that the airframe industry itself will reorient its design of derivative aircraft toward fuel conservation as a result of pressures from the airline industry even without a NASA fuel-conservative technology program the likely baseline scenario includes the future availability of more fuel-efficient aircraft. It is expected that market forces will lead to the introduction of a derivative medium range aircraft in about 1981 that is a replacement for the three engine narrow body turbofan aircraft. In 1985, a market should develop for a derivative long range aircraft that would begin to replace current four engine wide-body aircraft. Without a NASA program, it seems unlikely that a market would develop for a derivative short range aircraft.

Given the potential rate of technological development without the NASA program, which as mentioned previously is very difficult to estimate, it is likely that the medium range

baseline derivative appearing in 1981 would include some engine improvements (10-ton engine), composite secondary structures, active controls and wing aerodynamics to total about 8% savings over that of present medium range narrow body three-engine turbofan aircraft. In 1985 a baseline long range derivative may be expected to include all of the improvements included in the medium range derivative plus additional composites to result in a potential 9% fuel savings. (See Table 4.1)

4.2.2 Most Probable Scenario - The Fleet with the NASA R&D Program

While numerous possible scenarios of derivative and new aircraft introductions exist, the need for new aircraft by the airlines and the probable availability dates of compatible fuel conservative technologies yield the most likely scenario. With respect to aircraft type, derivative and new aircraft included:

Short Range: A first generation new aircraft prompted

Table 4.1 Baseline Scenario

Range	Type of Aircraft: Derivative	Type of Aircraft: New
Short	none	none
Medium	1981; 8% fuel saving composites (2.5%), wing aerodynamics (2%) active controls (2%), engine (2%)	none
Long	1985, 9% fuel savings composites (3.5%) wing aerodynamics (2%) active controls (2%), engine (2%)	none

by the availability of turboprops would appear in 1987. Since turboprops are best suited for short range application it seems possible that development would be accelerated slightly in order to meet the market demand appearing in the mid 1980's. In addition to turboprops this aircraft could incorporate aerodynamic improvements including active controls and some primary composite structure. Total likely fuel savings would reach 35% above present two-engine narrow-body turbofan aircraft.

Additional developments in turboprop core technology and composite structures would lead to the development by 1995 of a second generation new short range aircraft capable of a 45% fuel economy above present two-engine narrow-body turbofan aircraft. (See Table 4.2.)

Medium Range: Potential advances in composites would probably delay the introduction of a medium range derivative aircraft by one year until 1982 and result in an 18% fuel economy over present-day three-engine narrow-body jets. This improvement results from current engine developments (5%), composites (6%), active controls (4%) and wing aerodynamics (4%).

The market for a new medium range aircraft should develop by 1990 to take advantage of turboprop propulsion (20%) as well as improved core design (5%) active controls and wing

Table 4.2 The Fuel-Conservative Fleet		
	Type of Aircraft	
Range	Derivative	New
Short	1987*; 35% fuel savings turboprops (25%), aerodynamics and active control (8%) composites (8%)	1995**; 45% fuel savings turboprops and improved core (30%) aerodynamics (6%) composites (12%)
Medium	1982; 18% fuel savings current engine (5%), composites (6%) aerodynamics and active control (8%)	1995; 45% fuel savings turboprop and improved core (30%), aerodynamics and active controls (8%), composites (12%)
Long	1985; 24% fuel savings current engines (5%) active controls (4%) aerodynamics and laminar wing (9%) composites (8%)	1995; 45% fuel savings laminar flow control and aerodynamics (30%) composites (12%) fuel conservative engine (10%)

* first generation new aircraft in short range
** second generation new aircraft in short range

aerodynamics (7%) and primary structure composites (12%) to yield a 45% more efficient aircraft.

Long Range: A market for a derivative long range aircraft appears in the mid-1980 s (1985) and would achieve fuel savings as indicated from some primary structure composites (8%) active controls (4%) current engine improvements (5%) and a laminar wing with improved wing aerodynamics (9%), yielding a 24% more fuel efficient long range transport over present-day four-engine wide-body aircraft.

A new long range aircraft appearing in the mid-1990's (1995) could be 45% more fuel efficient than current wide-body

aircraft. This would result primarily from the successful development of laminar flow control (30%) plus primary composite structure (12%) other improved aerodynamics (active controls) (4%) and a fuel-conservative engine development (10%). Obviously, significant improvement over the derivative aircraft requires the successful development of laminar flow control. (See Table 4.2.)

Introduction dates for derivative aircraft were selected subject to:

- availability of fuel-conservative technology
- airline industry markets for replacement aircraft
- consideration of the airframe industry's tendency not to simultaneously develop aircraft in more than one range category.

Introduction dates for new aircraft considered only items (1) and (2) above since the nominal year of introduction (1995) is so far in the future.

5.0 PREDICTED FUEL CONSUMPTION

5.1 The Aircraft Replacement Model

The method for estimating the replacement of the existing fleet by new aircraft and the fuel consumed follows the same general approach as several previous studies of future fleet requirements. The first step is to forecast the demand for air travel in terms of revenue passenger miles (RPM). In this study we forecast RPM's for U.S. carriers for domestic operations only. International RPM's for U.S. carriers are assumed to remain a constant 25% of domestic RPM's through 2005. This demand was divided into short, medium, and long range categories. The number of aircraft in each category was calculated from the formula

$$N = \frac{RPM}{PROD \times LF}$$

where N is the number of aircraft, LF is the average load factor, and PROD is the average aircraft productivity in seat/miles per year. Aircraft were assumed to be retired after a fixed lifetime and new aircraft were added as required to meet the demand.

For each type of aircraft, annual fuel consumption was calculated from

$$GAS_i = GSM_i \times RPM_i \ / \ LF$$

where GAS_i is the annual fuel consumption in gallons and GSM_i is the gallons consumed per seat-mile for aircraft type i.

There are several parameters used in this model.

(1) The growth rate for forecasting travel demand.

(2) The division of travel demand and fleet for short, medium, and long range.

(3) The average productivity and fuel consumption (gallons per seat-mile) for each aircraft type.

(4) The scenario by which new aircraft are introduced; that is, year of introduction and percent fuel savings.

(5) The load factor.

(6) The depreciation lifetime.

Each of these is discussed below.

5.2 Model Parameters

5.2.1 Rate of Growth

Air travel was assumed to grow at a constant rate compounded annually over the thirty year study period, 1975-2005. This is a critical parameter which affects potential fuel savings exponentially. It is also an extremely uncertain parameter which is affected by all sorts of exogenous events which cannot be predicted. Most analysts of the airline industry use values between 4% and 7%. In this study, we have analyzed the fuel savings from a conservative 3% to an optimistic 8%. In accordance with the analysis described in Section 3.2, the baseline case is taken as 4.2%.

5.2.2 <u>Division by Range</u>

Both air travel demand and the domestic airline fleet were divided into short, medium, and long range. The choice of these categories was based on the analysis of operating data from the Civil Aeronautics Board (CAB).* These data showed that the average stage lengths of most aircraft fall into three relatively widely separated groups. Long range is defined as average stage length over 900 miles and includes the wide body jets (B-747, DC-10, L-1011), four engine turbofans (B-707, DC-8, B-720), and about 60% of four engine turbojets (B-707, DC-8, B-720, CV-880). Short range is defined as average stage length less than 500 miles and includes two engine turbofans (B-737, DC-9 and BAC-111) and turboprops. Medium range denotes average stage length between 500 and 900 miles; this category includes three engine turbofans (B-727) and about 40% of the four engine turbojets.

In 1974, the breakdown of domestic air travel demand by RPM was approximately 50% long range, 35% medium range, and 15% short range. These percentages were assumed to remain the same over the thirty year period examined.

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*Aircraft Operating Cost and Performance Report, Civil Aeronautics Board, June, 1974.

5.2.3 Operating Data

As suggested above, six different aircraft types were identified: wide-body jets, four engine turbofans, three engine turbofans, two engine turbofans, four engine turbojets and turboprops. Each type aircraft was defined by two parameters:

(a) productivity in seat-miles/year. This is the product of block speed (miles/hour), capacity (seats), and utilization (operating hours/year).

(b) fuel consumption (gallons/seat-mile).

These parameters were determined by weighted averages of CAB operating data. For purposes of this study, productivity is not especially critical since it does not affect total fuel consumption. It does, however, affect the number of aircraft in each category, and thus, it can be used as a check on the projections. Essentially the model forecasts the number of passenger-miles, which when divided by load factor become seat-miles, and multiplied by fuel consumption become gallons of fuel. Productivity only affects the way these seat-miles are "packaged" into aircraft.

5.2.4 Scenario for New Aircraft

New aircraft are defined by three parameters: in addition to productivity and fuel consumption, one must specify the year of introduction. Since productivity has no effect on total fuel consumed, it was assumed constant for each of the three range

categories except for the new long range aircraft for which it was assumed to increase by 20% due to higher seating capacity. Thus the two key parameters are fuel consumption (GSM) and year of introduction (IY). Three types of "new" aircraft are used to fill the gap in travel demand:

(a) Continuing production of existing aircraft. For long range, this is assumed to be the wide-bodies; for medium range, three engine turbofans; and for short range, two engine turbofans.

(b) Derivatives which include evolutionary improvements to existing models and

(c) New aircraft which incorporate the results of the proposed research program.

Two scenarios were considered. The first incorporates fuel conservation technology that would be introduced by the airframe and engine manufacturers without the NASA research program. Essentially, this is technology which is ready for implementation at the present time. This scenario is given below:

	IY	ΔGSM
Short Range	no change	
Medium Range Derivative	81	-8%
Long Range Derivative	85	-9%

The second scenario incorporates the fuel saving technology of the NASA research program:

		IY	ΔGSM
Short Range	New	87	-35%
	New	95	-45% (from 1975)
Medium Range	Derivative	82	-18%
	New	90	-45% (from 1975)
Long Range	Derivative	85	-24%
	New	95	-45% (from 1975)

The development of this scenario is discussed more fully in Section 4.2.

5.2.5. Load Factor

We have assumed an average load factor of 55% in this analysis, but also show the effect of alternate assumptions of average load factors up to 65%. It is necessary to explain these assumptions, particularly in light of recent lower industry average load factors (52.7 percent averaged over the last ten years, and 51.2 percent averaged over the past five). A brief background discussion is appropriate.

In 1971 the Civil Aeronautics Board (CAB) reviewed load factors that had been experienced by the industry and decided that basing fares on actual load factors contributed to over-capacity. As load factors declined (and they did so during the late 1960's) average costs per passenger increased, justifying fare increases. This worsened the problem both by lowering breakeven load factors

(causing more service to be added), and by driving away passengers. This required further fare increases. The CAB reasoned that by instituting a "standard" load factor for fare setting purposes - they chose 55 percent - that breakeven load factors would no longer decline and the downward trend in capacity utilization would be halted.

The policy had its intended effect of stopping the downward trend in load factors. Nevertheless, the carriers continued to operate nearer to breakeven load factors of 50-52 percent than to the profitable load factors of 55 percent envisioned by the CAB.*

Several trends are manifesting themselves now, and all tend to increase load factors. The first is pressure on the CAB to limit both aircraft fuel consumption and further fare increases by taking steps to improve aircraft occupancies. A proceeding is now under way to consider raising the load factor standard to 60 or 65 percent for fare setting purposes. Very likely the more moderate 60 percent standard will be adopted — at this level few can complain of high incidences of sold out flights. Even at 65 percent, with some fare-based incentives to smooth the demand, adequate service is provided. Although a 60 percent standard would not necessarily produce 60 percent load factors (for reasons

*The discrepancy is caused by the carriers' propensity to add services whenever a profitable opportunity appears - and the profitability need not be nearly as high as the 12 percent return on investment that enters into the CAB's determination of the proper fare for a 55% load factor.

explained in the footnote), it would raise load factors to 55 percent, or greater.

The second factor entering into higher load factors is the growing use of discount fares by carriers as a tool both for building traffic and smoothing demand variations. This has the effect of raising load factors because breakeven load factors increase (the average passenger fare is less than before).* Since the fare setting process is based on standard loads at normal (undiscounted) fares, the increased proportion of discount passengers tends to push load factors up toward or even beyond the CAB's standard, which we believe will soon be 60%.

A further upward push on average load factors is the recently approved operation of one stop tour charters. These flights, by definition, fly at 100% load factor, both stimulating some new traffic (because of reduced fares) and diverting some of it from scheduled service. It is too early to measure the popularity of these charters, their impact on average fares, total demand, scheduled services, and average load factors. European experience with a similar concept suggests a very large potential market, but it may be argued that Americans may not readily accept

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*As breakeven load factors increase, load factors must increase, even if new traffic did not appear. In such a case more flights would lose money, and carriers would begin to reduce their schedules, raising average load factors. Of course, if enough new traffic appears, this will raise load factors without schedule cutbacks.

the very low cost ground accommodations on which low cost inclusive tours are based. It is also questionable whether as many opportunities exist to create low cost domestic destinations as is the case in the Mediterranean. Certainly some allowance must be made for an impact of the long-delayed tour charter into the U.S. domestic market — the only question is how much. The forecast of declining yields per passenger is based partly on the growth of the charter proportion of air traffic, and to be consistent, we should adjust average load factors upward.

Taking all of the factors mentioned above into account, we must pose the likelihood of average load factors being not the 'standard' 55 percent 10 years hence, but somewhere in the vicinity of 60%. For these reasons we have considered 60% as an alternate to the 55 percent load factor widely accepted by airlines, aircraft manufacturers, and until now the CAB for planning purposes.

5.2.6 Aircraft Replacement

In this analysis we have assumed that aircraft in the existing fleet are retired after 15 years in service. This is certainly a simplification of a complex picture, yet it is based on considering the whole picture. We do not rest on an assumption that aircraft serve out their "depreciation lifetimes" and then are replaced.

First of all, it should be stated that under continuing maintenance cycling, aircraft have an indefinitely long physical lifetime. DC-3's originally introduced in the 1930s, DC-6's and DC-7's of the 1940's and 1950's are still flying in scheduled airline service in parts of the world, while the 707's introduced in the late 1950s in the U.S. are nowhere near "wear-out". Airlines contemplating keeping some of their 707's in service past 60,000 service hours (about 20 years) are now planning some structural reworkings that may cost about $250,000 per plane (vs. the current purchase price of about $10 million). This will extend their potential airworthiness at least 20,000 hours, or about 7 years. Other jet aircraft are not known to require even such minor structural reworkings. Apart from structure, maintenance cycle costs are a year-in, year-out function of aircraft usage, rather than age, so there is never an advantage to replacing an old aircraft with a newer one of the same design.

Secondly, we should consider financial lifetime - in the sense of the duration of tax benefits. Airlines, as do other companies, normally receive an investment tax credit upon purchase of an aircraft.* They are also allowed to depreciate their equipment over a six to eight year lifetime for tax purposes, on an accelerated schedule for the first several of these years

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*In some cases this may pass to a bank or a leasing company, which is of no consequence in this context.

("double declining balance method"). After this time tax savings for the purchase of these aircraft end, but if new replacement aircraft are purchased, the tax benefits begin again. If this were the dominant factor, aircraft would be replaced every six to eight years.* Clearly they are not, but the tax considerations are an incentive that certainly enters the total evaluation of aircraft replacement. It should be mentioned that the "book depreciation" period of 12 to 16 years is separate from the tax depreciation matter, and will be considered below.

Thirdly, we must consider <u>technological</u> lifetime, meaning, in the broad sense, the period over which an airline feels it has the best available aircraft to suit its needs. When a new aircraft type enters the picture, the old one is "obsolete" to the extent that the airline prefers the new one for whatever reason: seating capacity, range, appearance, operating cost, or some combination. This is the real driving force behind aircraft replacement, pushed, as the case may be, by tax considerations, and restrained, in some cases, by lack of funds. But when funds are not the governing restraint, an airline may phase in and phase out a fleet of aircraft within relatively few years. American Airlines, for example, took delivery of the BAC-111 in

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*If this were to be typical, airlines would probably lease out their old aircraft for a number of years rather than selling them, in order to avoid paying taxes on large sales receipts relative to depreciated values.

1966, and had replaced them all by 1973; they received their 720-B's in 1961, and had replaced all but a few by 1971. United received its 727 'Quick Change' aircraft in 1966-67, and is currently phasing them out; and it had replaced its 1961 fleet of Caravelles by 1972. The 747's, to a degree, replace 707's and DC-8's that range from 15 down to only seven or eight years old, and now, only five years after introduction, these 747's are being replaced in some cases by DC-10's and L-1011's. Manufacturers are in business to make old aircraft obsolete by whatever combination of appeals will best serve the purpose. Certainly economy of operation is one such appeal, as well as other features such as seating, flexibility, and range. Manufacturers, of course, have their own concept development, engineering, marketing, and production cycles governed by their own investment considerations, but they usually have new product concepts in readiness whenever they feel the market is ripe.

This, of course, brings into question the ability of the airlines to finance new fleets — especially given the poor financial health of some carriers. A carrier has available to it three sources of funds: internally generated funds, debt, and equity. The internal funds come from profits, plus revenues designated as "depreciation" rather than labeled as "profits". (This is the "book depreciation" — usually an annual 1/12th to 1/15th of the purchase price down to some small residual value.)

Depreciation of domestic fleets accounts for about $750 million in funds annually, but profits fluctuate widely. In 1974 all U.S. carriers together earned $321 million after taxes, but in 1975 losses are projected at $300 million, and these are expected to double in 1976.* Obviously, internal funds for equipment purchase are not accumulating rapidly under current conditions - but current conditions cannot continue. Most likely the current problems, which are primarily traceable to fuel cost increases, plus excessive ordering of new aircraft when the country was heading into a recession, will work themselves out in a few years. If not, it seems almost inevitable that through industry restructuring, deregulation, or subsidy, the industry will return to generating "normal" amounts of internal funds, so that on the order of $1 billion to $1.5 billion annually will become available. Some of these funds, of course, must be used to purchase other equipment and facilities, and some used for dividends, but possibly $500 to $750 million would remain for aircraft investments.

Debt financing provides a second source of funds, which on an industry basis provides as much or more funding than the internal funds. In view of the dubious value of Pan Am's and Eastern's debt, banks and insurance companies are currently wary of lending to the weaker airlines. Nevertheless, it seems reasonable to assume that either the weak airlines will be strengthened

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*Wall Street Journal, August 21, 1975.

soon by acquisition or the Government will underwrite their debt. Very likely, under these circumstances, debt will continue to provide the order of $1 billion annually in aircraft financing capability.

A third funding source is equity. For the strongest airlines, such as Delta and Northwest, raising funds by issuance of stock is feasible but unnecessary. The stock of other carriers is currently selling well below book values, so that it is very unattractive for most airlines to raise capital in this manner. While conditions may change, this is the least certain source of funds, and is probably best ignored.

Of course aircraft need not be <u>purchased</u> by airlines — third parties can lease them to the carriers, and frequently do. (The third parties are often subsidiaries of banks or insurance companies.) The major concern of the owning parties is obtaining sufficiently long leasing lifetime to justify the investment, which is similar to the airlines' own criteria. Leasing sources may be expected to have very large funding available provided that the long term picture of the industry improves.

Taking the funds <u>directly</u> available to the airlines, as stated above, complete fleet replacement can occur in 12-15 years, and leasing parties potentially will provide further funds if weak participants are absorbed or underwritten.

Summarizing the above discussions, we might say that it is safe to assume that aircraft replacements will occur after

15 years service life, but that with the aggressive product development and marketing of aircraft manufacturers, 10-12 years is probably a better assumption. Use of such a shorter replacement cycle would bring new aircraft on-stream sooner and, if these aircraft are fuel conservative, generate larger fuel savings than with a 15-year replacement cycle.

5.3 Results

5.3.1 Baseline

For the baseline case, a relatively conservative growth rate of 4.2% per year was chosen as discussed previously. The load factor was taken as 55% and aircraft lifetime 15 years. With these assumptions (for the U.S. domestic and U.S. international operations) the cumulative fuel consumed to 2005 is 332.6 billion gallons with the NASA program, and 422.9 billion gallons without, a savings of 90.3 billion gallons or 21% over the thirty-year period. By 2005 the annual fuel consumption is 13.9 billion gallons with the NASA program and 23.0 without, a saving of 9.1 billion gallons or 40% annually. Total fuel consumed under both scenarios and fuel savings, annual and cumulative, are shown in Table 5.1. Figure 5.1 illustrates the jet fuel consumed by the U.S. domestic and international commercial air transportation fleet with and without the impetus of the NASA sponsored fuel conservative technology program, and its relationship to the current rate of U.S.

Table 5.1 Future Fuel Consumption and Savings

Year	Fuel Consumption With NASA R&D in billions of gallons: Per Year	Cumulative	Fuel Consumption Without NASA R&D in billions of gallons: Per Year	Cumulative	Fuel Savings in billions of gallons: Per Year	Cumulative
1976	8.08	8.08	8.08	8.08	--	--
1977	8.34	16.42	8.34	16.42	--	--
1978	8.66	25.08	8.66	25.08	--	--
1979	8.98	34.06	8.98	34.06	--	--
1980	9.30	43.36	9.30	43.36	--	--
1981	9.65	53.01	9.61	52.97	-.04	-.04
1982	9.85	62.86	9.94	62.91	.09	.05
1983	10.10	72.96	10.3	73.21	.20	.25
1984	10.36	83.32	10.68	83.89	.31	.56
1985	10.42	93.74	11.00	94.89	.57	1.13
1986	10.55	104.29	11.36	106.25	.81	1.94
1987	10.69	114.98	11.68	117.93	.99	2.93
1988	11.04	126.02	12.19	130.12	1.15	4.08
1989	11.40	137.42	12.66	142.78	1.26	5.34
1990	11.49	148.91	13.10	155.88	1.59	6.93
1991	11.69	160.6	13.59	169.47	1.90	8.83
1992	11.94	172.54	14.09	183.56	2.15	10.98
1993	11.94	184.48	14.58	198.14	2.64	13.62
1994	11.95	196.43	15.06	213.20	3.11	16.73
1995	11.69	208.12	15.62	228.82	3.94	20.67
1996	11.58	219.70	16.2	245.02	4.62	25.29
1997	11.62	231.32	16.82	261.84	5.20	30.49
1998	11.81	243.13	17.47	279.31	5.69	36.18
1999	11.92	255.05	18.18	297.49	6.25	42.44
2000	12.10	267.15	18.91	316.40	6.81	49.25
2001	12.32	279.47	19.66	336.06	7.34	56.59
2002	12.69	292.16	20.45	356.51	7.76	64.35
2003	13.09	305.25	21.26	377.77	8.17	72.52
2004	13.45	318.70	22.12	399.89	8.67	81.19
2005	13.88	332.58	23.00	422.89	9.12	90.31

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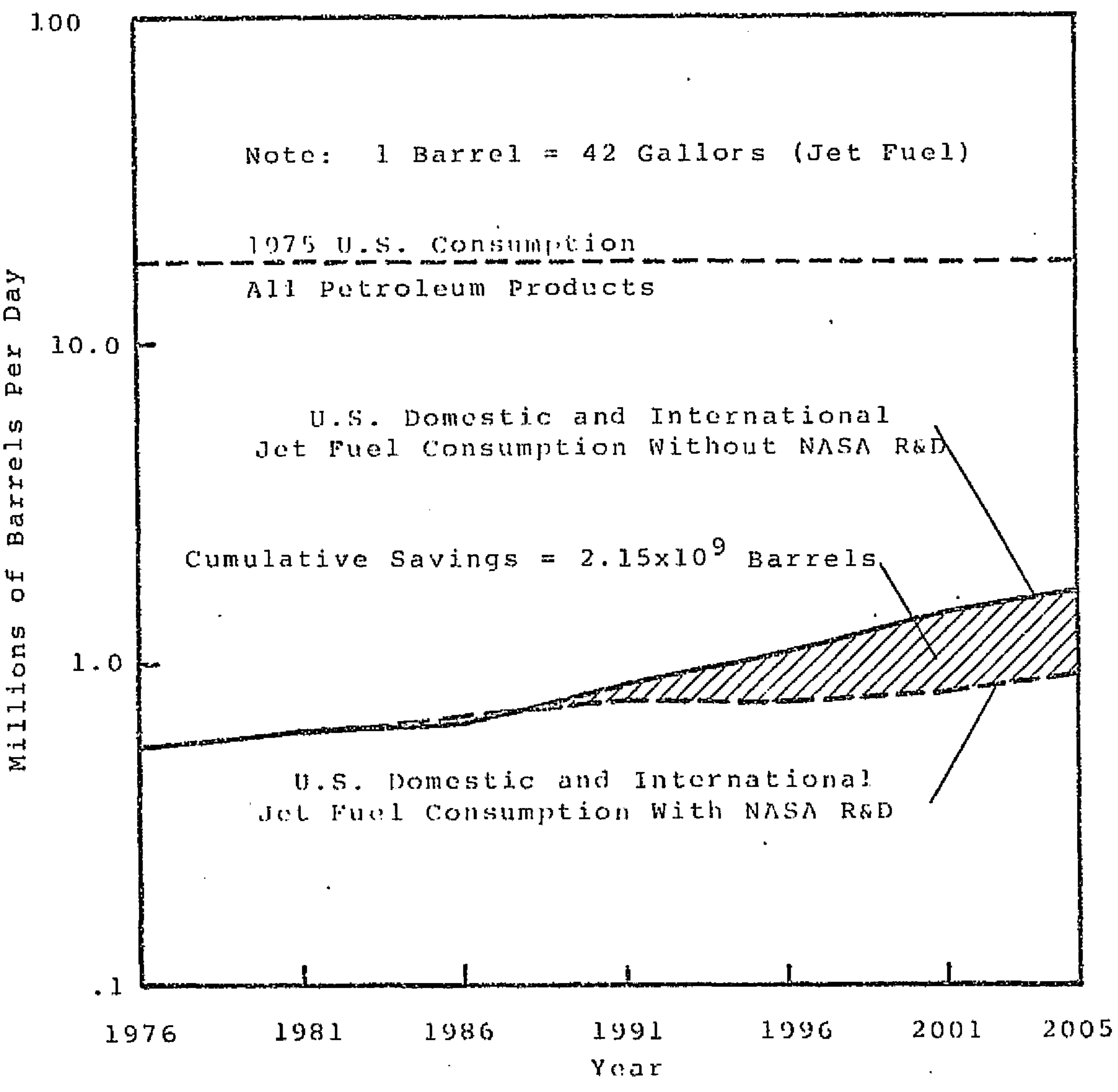

Figure 5.1 Fuel Used by the U.S. Domestic and International Airtransport Fleet

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consumption of petroleum products. While the U.S. rate of consumption of energy from all sources will increase in this time period, the rate of consumption of petroleum products may actually decrease as a result of the use of substitute energy sources and conservation measures. Figure 5.2 is a plot of the fuel savings over the thirty year period.

It is estimated that the aircraft fleet (U.S. domestic and U.S. international) in 2005 will number 3559 with the NASA program and 3696 without, a difference of 137 which is due to the greater productivity assumed for the new long range aircraft. By range category, the fleet breaks down as follows:

	With NASA Program	Without NASA Program
Long Range	716	826
Medium Range	1472	1472
Short Range	659	659

Projected replacement is slightly less than 10% of the fleet annually; net change in the fleet is about 3.5% annually.

The remaining paragraphs in this section quantify the sensitivity of these projections to each of several critical parameters.

5.3.2 Rate of Growth

Fuel savings were calculated for a range of growth rates from 3% to 8%. The results are presented in Table 5.2

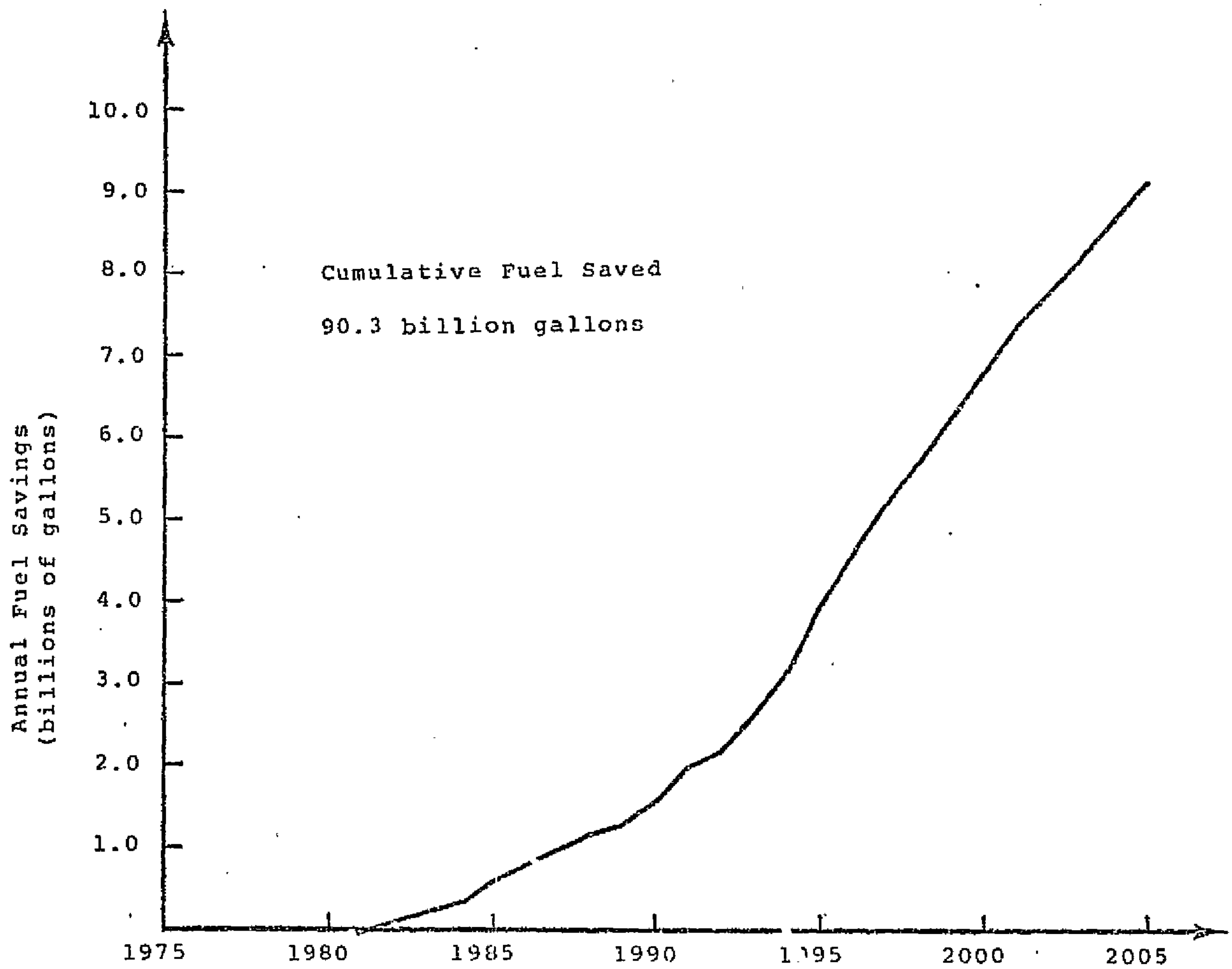


Figure 5.2 Annual Fuel Savings From NASA R&D Program

Table 5.2 Variation in Fuel Consumption with Rate of Growth, gal.x10^9

Growth Rate	With NASA Program	Without NASA Program	Savings	Percent Savings
		Cumulative (1975-2005)		
.03	284.80	356.16	71.36	20.1
.042*	332.59	422.89	90.31	21.4
.05	390.30	504.78	114.48	22.7
.06	460.19	605.12	144.94	23.9
.07	545.00	728.44	183.44	25.1
.08	648.19	880.20	232.01	26.3
		Annual (2005)		
.03	10.39	17.21	6.82	39.6
.042*	13.88	23.00	9.12	39.7
.05	18.46	30.65	12.19	39.8
.06	24.50	40.74	16.24	39.9
.07	32.42	53.99	21.56	39.9
.08	42.80	71.38	28.58	40.0

* baseline case

and plotted in Figure 5.3. Basically, they indicate that potential fuel savings increase exponentially with growth rate: cumulative savings range from 71.4 billion gallons at 3% to 232.0 billion gallons at 8%; annual savings in 2005 range from 6.8 billion gallons at 3% to 28.6 billion gallons at 8%. Percentage savings increase about 1.3 percentage points for each point increas in growth rate for cumulative fuel consumed (from 20% to 26%). Percentage fuel savings annually in 2005 are relatively constant with growth rate (at about 40%).

5.3.3 Load Factor Assumptions

Because of the arguments presented earlier, fuel consumption for a range of load factors up to 65% were calculated. As expected, fuel consumption decreases with increasing load factor from 90.3 billion gallons at 55% load factor to 82.9 billion gallons at 60%. Percentage savings are relatively constant at 21%. The results are shown in Table 5.3 and plotted in Figure 5.4.

5.3.4 Year of Introduction

Sensitivity to delays in implementation of the fuel conservative aircraft program were explored by calculating fuel consumed if the NASA program were delayed by one year and two years. In this case, we assume the entire scenario was delayed by a uniform amount: all derivative aircraft introduced a year later and all new aircraft introduced a year later.

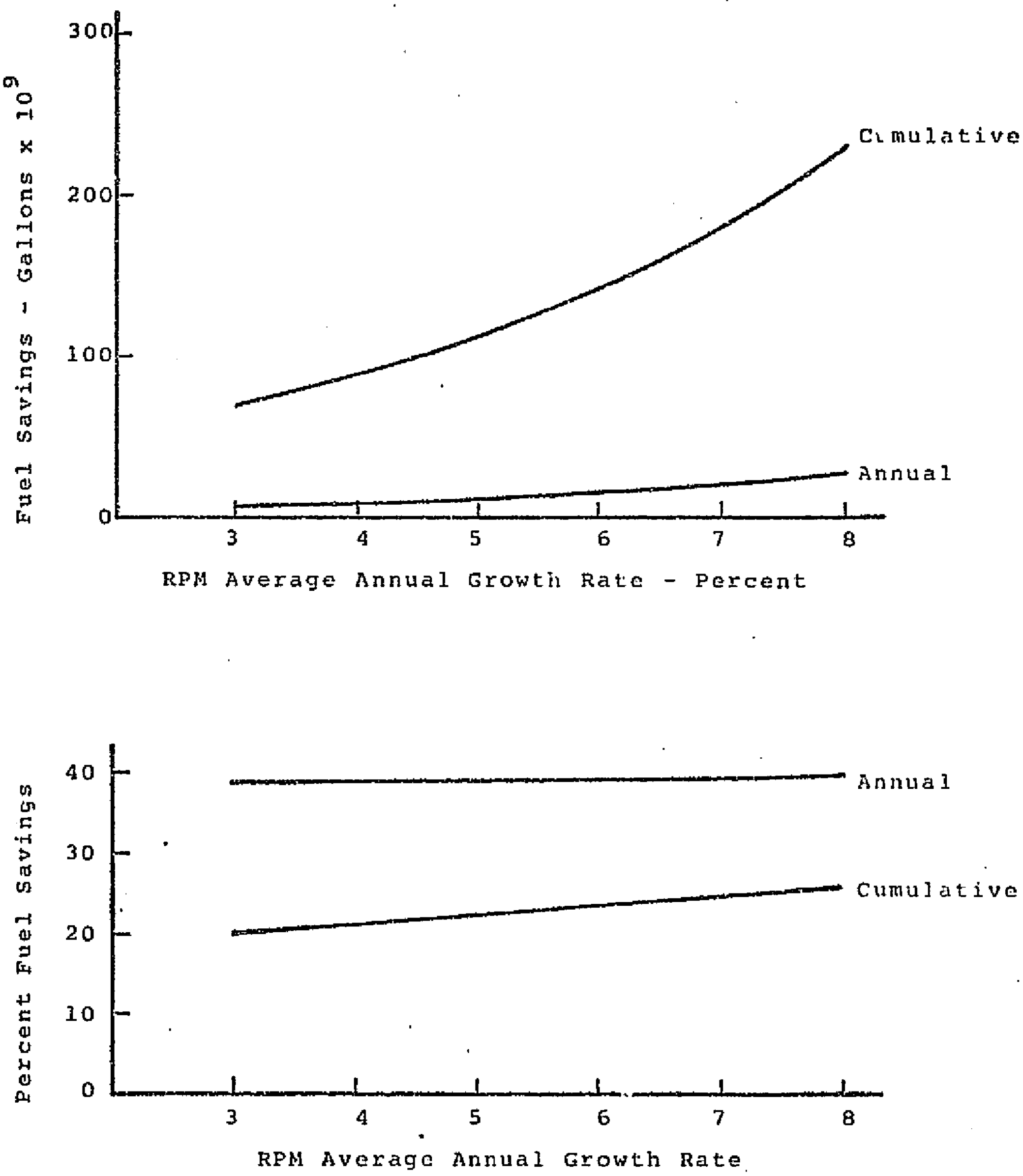
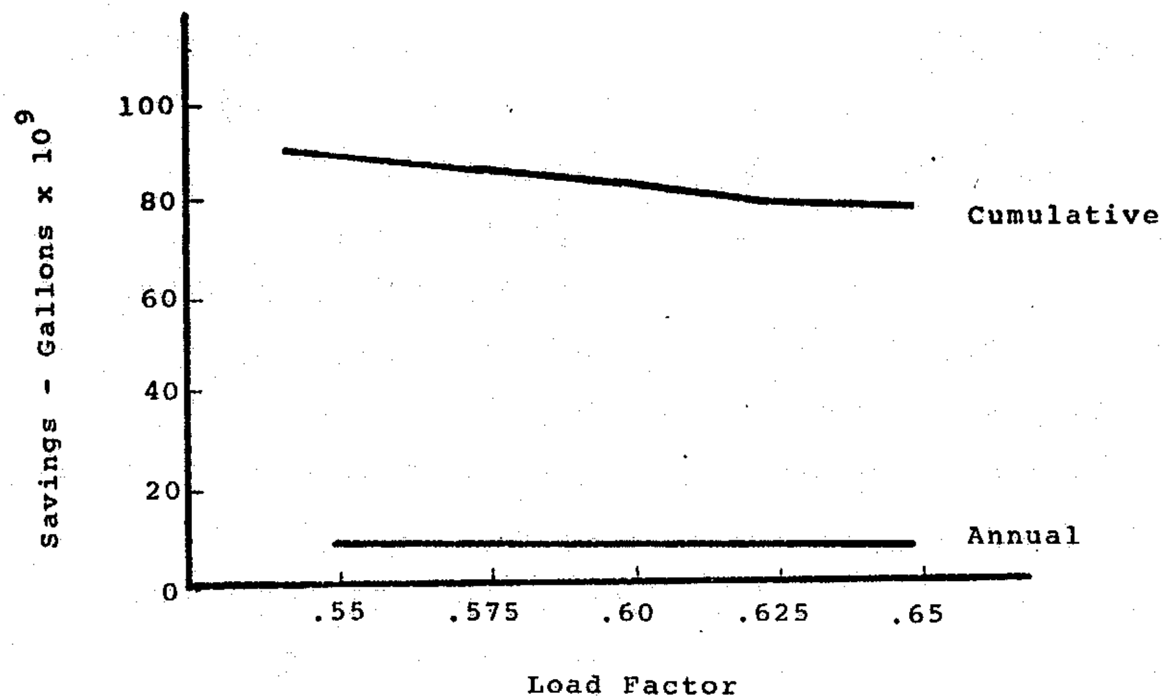


Figure 5.3 Variation in Fuel Consumption with Rate of Growth for U.S. Domestic Operation

Table 5.3 Variation of Fuel Consumption with Load Factor, gal.x10^9

Load Factor	With NASA Program	Without NASA Program	Savings	Percent Savings
		Cumulative (1975-2005)		
.55	332.59	422.89	90.31	21.4
.575	318.16	404.58	86.41	21.4
.60	304.85	387.71	82.86	21.4
.625	292.34	372.15	79.81	21.5
.65	280.66	344.35	77.05	21.5
		Annual (2005)		
.55	13.88	23.00	9.12	39.7
.575	13.27	22.00	8.72	39.7
.60	12.72	21.09	8.36	39.7
.625	12.22	20.24	8.01	39.6
.65	11.76	19.46	7.69	39.5



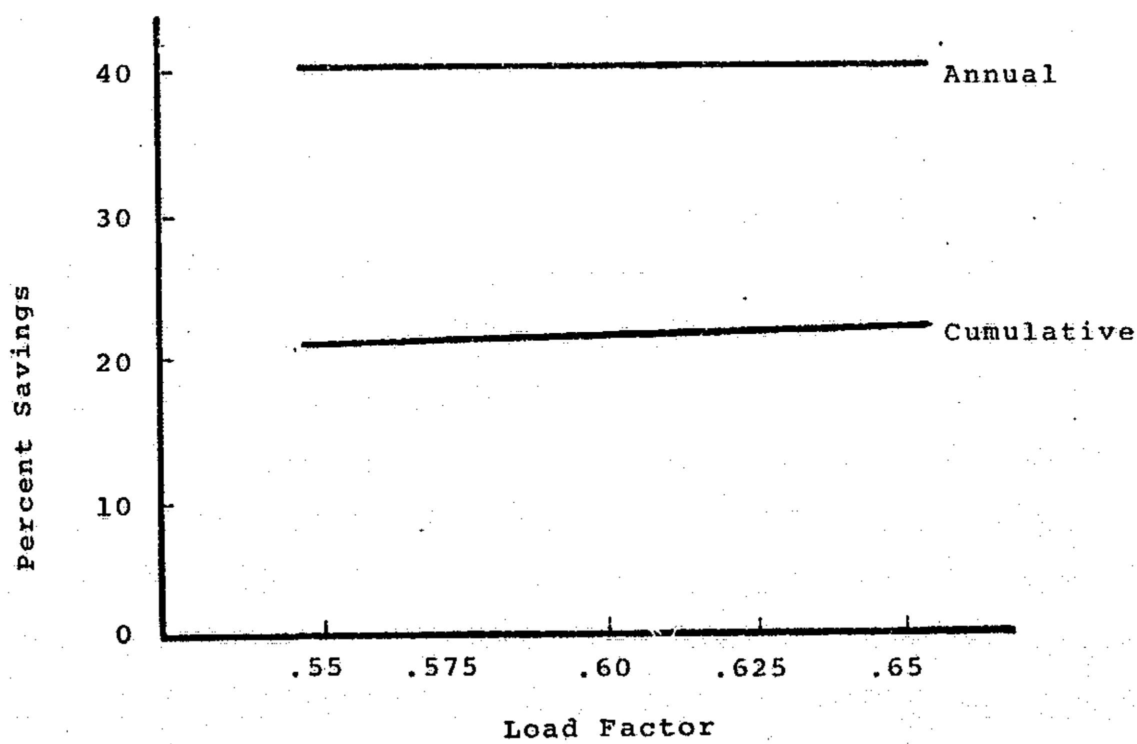


Figure 5.4 Variation in Fuel Savings with Load Factor

The data are presented in Table 5.4 and plotted in Figure 5.5. Basically each year delay causes an increase in fuel consumption of about 8 billion gallons cumulatively and a corresponding decrease in fuel savings.

Sensitivity to the delay of acceleration of individual aircraft was also examined. Delay of the long range aircraft (scheduled for 1995) for one year would cost 1.7 billion gallons over the period 1995-2005. Similarly, delay of the medium range aircraft (scheduled for 1990) for one year would cost 1.35 billion gallons from 1990 to 2005. Delay of the short range aircraft (scheduled for 1995) would cost .38 billion gallons (1995-2005). Accelerating the schedule would save corresponding amounts.

5.3.5 Gallons Per Seat-Mile

The objective of the NASA program is to achieve reductions in specific fuel consumption for derivative and new aircraft (e.g., 45% in the new aircraft). Sensitivity of the totals to shortfall of these target values of the NASA R&D program was explored by calculating fuel consumed with a 5% and 10% increase in specific fuel consumption of new aircraft above the target values. Similarly, the savings which would result from surpassing the target goals by 5% and 10% were explored. The results are shown in Table 5.5 and plotted in Figure 5.6. An increase of 5% in fuel consumption above the target values costs about 9.5 billion gallons cumulatively

Table 5.4 Variation of Fuel Consumption with Year of Introduction, gal.x10^9

	With NASA Program	Without NASA Program	Savings	Percent Savings
		Cumulative	(1975-2005)	
On Schedule	332.59	422.89	90.31	21.4
Delay One Year	341.45	422.89	81.52	19.3
Delay Two Years	349.39	422.89	73.59	17.4

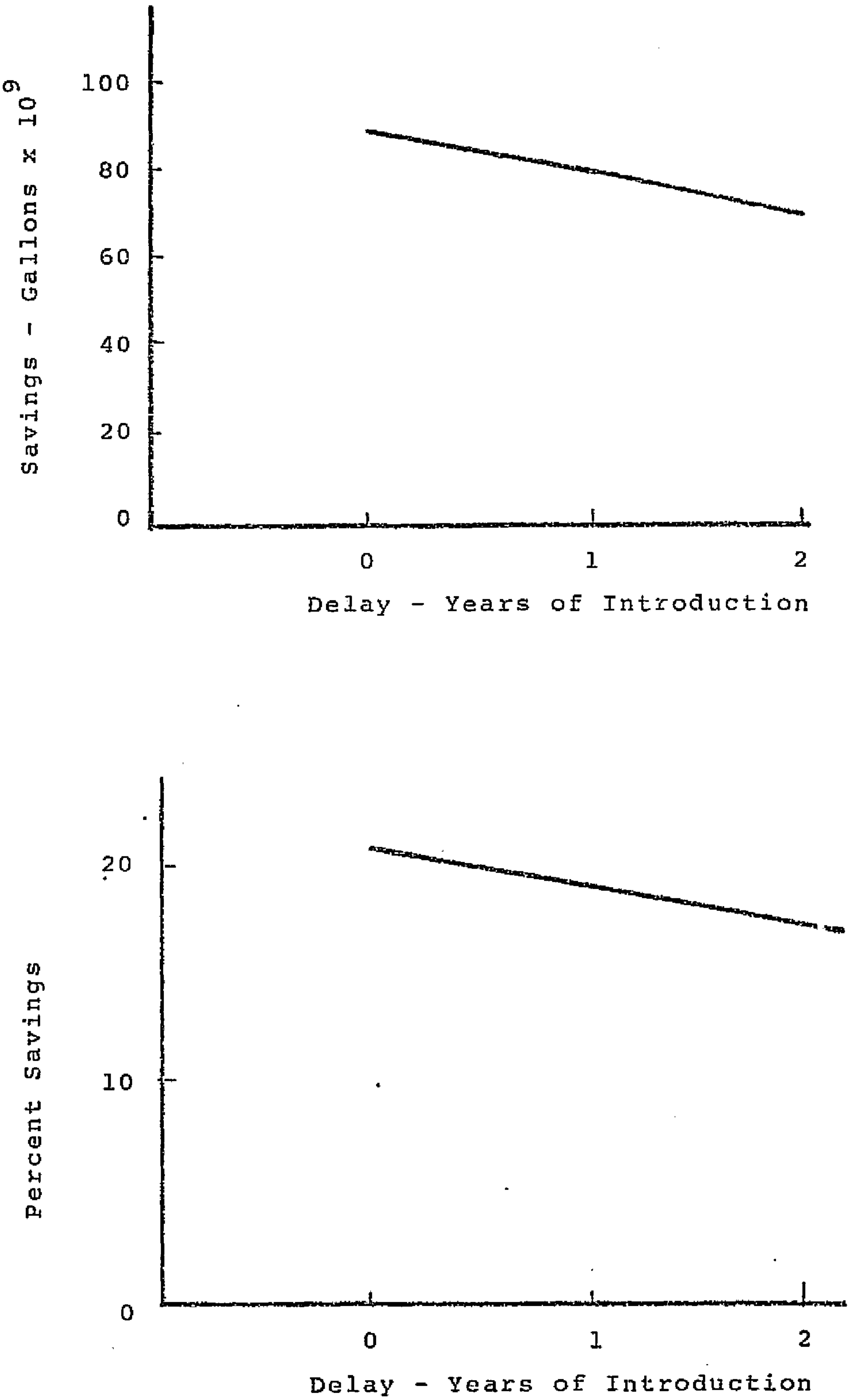


Figure 5.5 Variation in Fuel Savings with Year of Introduction

Table 5.5 Variation of Fuel Consumption With Gallons Per Seat-Mile, gal.x10^9

Gallons Per Seat Mile	With NASA Program	Without NASA Program	Savings	Percent Savings
		Cumulative (1975-2005)		
Decreasing Fuel Consumption -10%	314.12	422.89	108.85	25.7
- 5%	323.12	422.89	99.85	23.6
Base	332.59	422.89	90.31	21.4
5%	342.06	422.89	80.91	19.1
10%	352.00	422.89	70.98	16.8
		Annual (2005)		
Decreasing Fuel Consumption -10%	12.52	23.00	10.48	45.5
- 5%	13.18	23.00	9.82	42.7
Base	13.88	23.00	9.12	39.7
5%	14.56	23.00	8.44	36.7
10%	15.30	23.00	7.70	33.5

Table 5.6 Variation of Fuel Consumption With Aircraft Lifetime, gal x 10^9

Aircraft Lifetime (years)	With NASA Program	Without NASA Program	Savings	Percent Savings
		Cumulative		
15	332.59	422.89	90.31	21.4
18	345.65	425.51	79.86	18.8
20	348.79	426.55	77.76	18.5

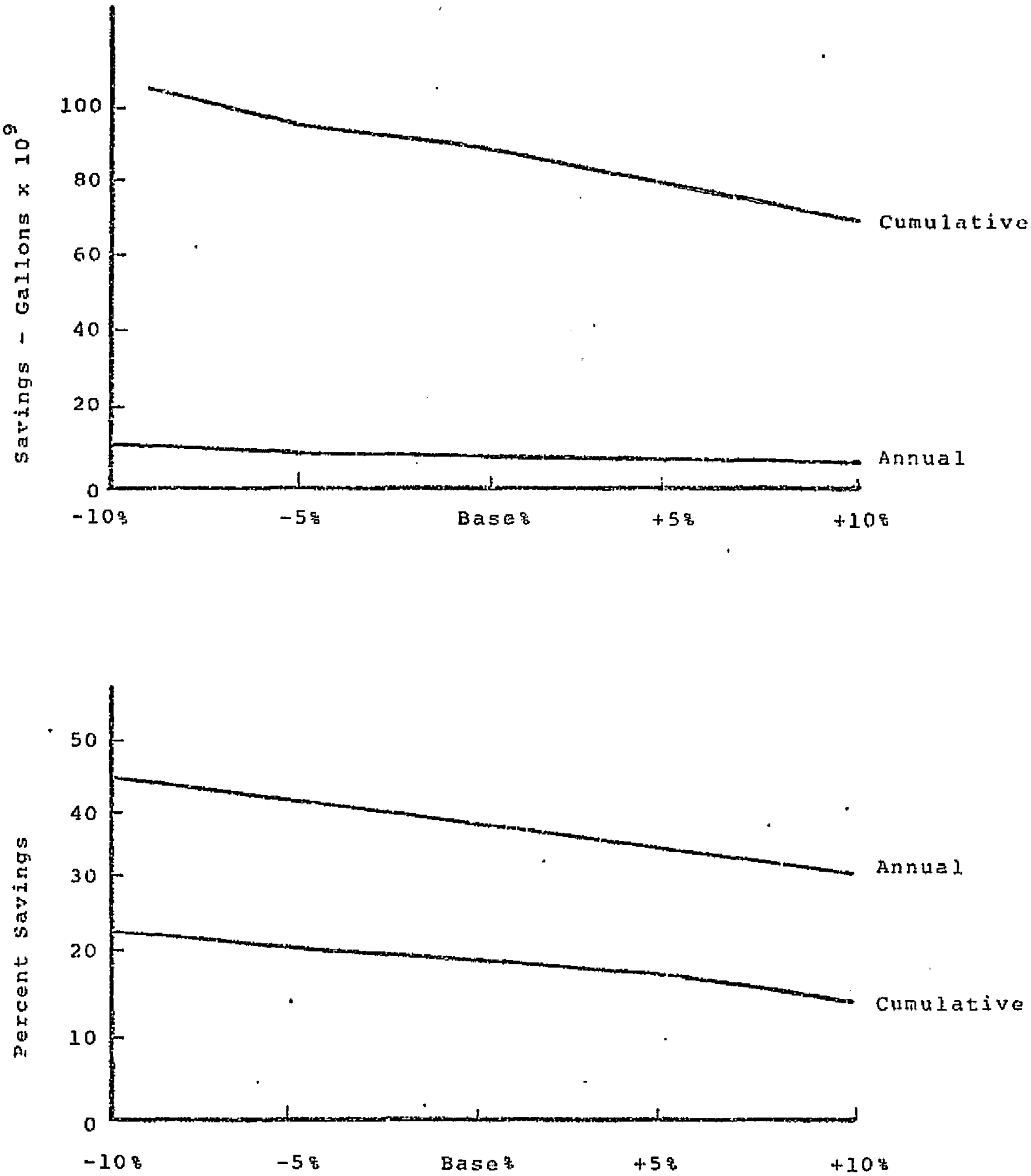
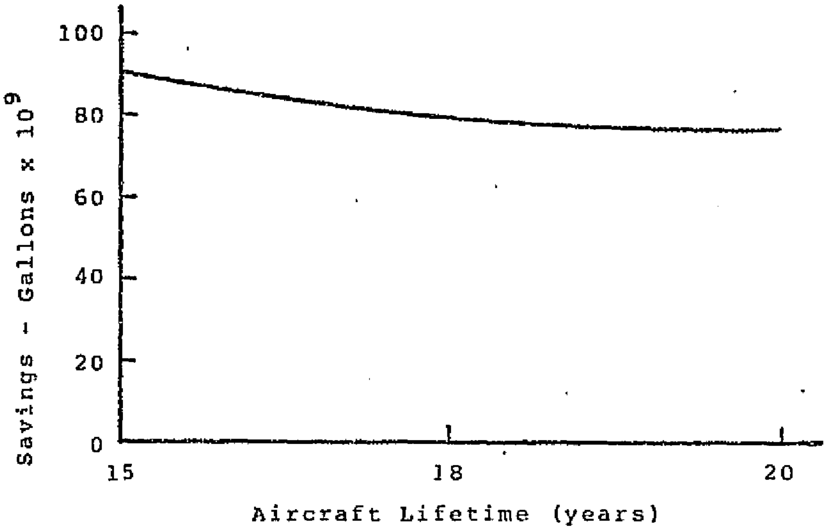


Figure 5.6 Variation in Fuel Savings with Fuel Consumption Targets

over the 30-year period and about 680 million gallons annually in 2005; an increase of 10% above the target values costs another 10 billion gallons cumulatively and 740 million gallons annually. Conversely, surpassing the target values by 5% saves 9.4 billion gallons or about 700 million gallons in 2005.

5.3.6 Aircraft Lifetime

Sensitivity to the assumption of 15-year aircraft lifetime was determined by calculating savings for 18 and 20 year lifetimes, respectively. As excepted, fuel consumption increases with increasing lifetime, both with and without the NASA program since older, less fuel-efficient aircraft are replaced more slowly. Savings decrease from 90.3 billion gallons with a 20-year lifetime. The data are shown in Table 5.6 and plotted in Figure 5.7.



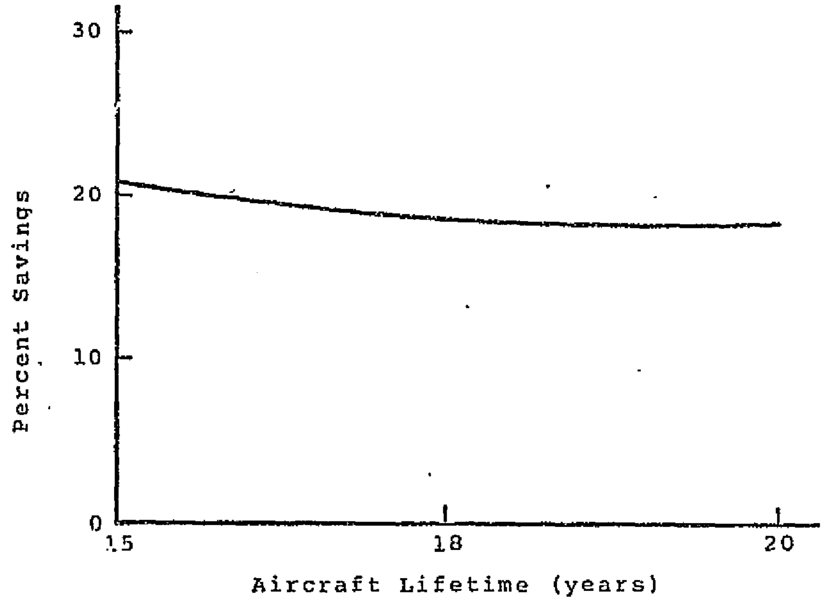


Figure 5.7 Variation of Fuel Savings with Aircraft Lifetime

6.0 BENEFITS AND COSTS OF THE NASA FUEL CONSERVATIVE AIRCRAFT TECHNOLOGY PROGRAM

6.1 Benefits From U.S. Domestic Air Travel

Conservation goals are aimed at saving physical resources. Therefore, dollar units by themselves may not be appropriate measures of conservation benefits - especially when the future valuation of price of the resource is subject to great uncertainty. In order to put this uncertainty into perspective, benefits are estimated in two ways: the first, using traditional present value techniques under two different pricing assumptions for jet fuel and for two corresponding discount rates, 5% and 10%; the second, in terms of physical resources, gallons of fuel, over the thirty year period.

Fuel savings are calculated by comparing fuel consumption for two scenarios. The first assumes the fleet that would be in existence with implementation of the NASA program. The second includes expected technology advances and fuel efficiency increases which would be achieved by private industry without the NASA program. Therefore, the savings are those attributable to the NASA program alone. The fuel savings are shown in Figure 5.2. A conservative 4.2% growth in demand is employed.

Over the 30 year period there is a cumulative savings of 72.2 billion gallons in U.S. domestic operations. Assuming a

daily consumption of 17 million barrels per day for the total U.S. economy for all uses of petroleum, this savings could supply all U.S. needs for 107 days at the present rate of consumption, or could supply U.S. domestic passenger air transportation for more than eleven years at the current (1974) rate of consumption.

However, due to the long R&D lag inherent in the industry, benefits do not accrue in any substantial amount until after 1985. In present (1975) dollar terms the total benefits over the life of the transferred technology are $9.4 billion. (See Figure 6.1.) When the benefit from the U.S. international sector (see Sec. 6.2) are added to the benefits obtained in the U.S. domestic sector, the present value of the total gross benefit from U.S. fuel savings is $11.7 billion ($1975). These benefits were derived by converting the physical fuel savings to dollar values by assuming that by 1980 U.S. domestic jet fuel prices would increase to the present international level of 35 cents per gallon and thereafter would increase at an annual rate of 7%. This fuel price increase is in line with a discount rate of 10%. The combination of these two effects implies that one gallon of jet fuel in 1985 has a present value ($1975) of 18.9 cents; in 1990, 16.5 cents; and in 2000, 12.5 cents. If on the other hand, it is assumed that the price of jet fuel in the U.S. remains constant at 22 cents per gallon through the year 2005, the present value of the benefit ($1975)

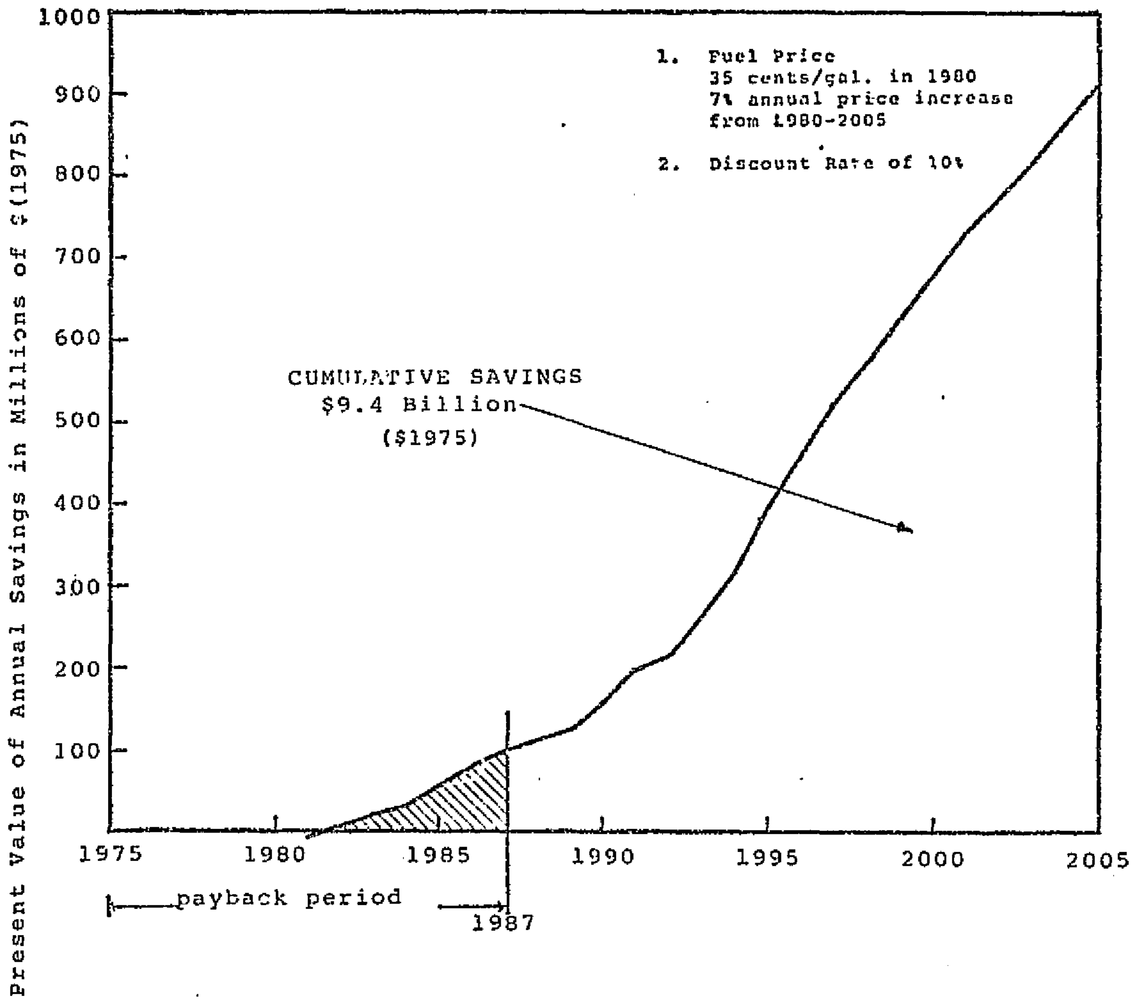


Figure 6.1 Benefits in Present Value Dollars of Annual Fuel Saved in U.S. Domestic Operations

accruing from savings in both U.S. domestic and international commercial air operations is $2.7 billion at a 10% discount rate, and $6.4 billion at a 5% discount rate. This implies that the present value ($1975) of a gallon of jet fuel in 2000 is 2.0 cents at a discount rate of 10%.

The cost of the proposed baseline and Level II NASA programs are $670 million to be allocated over a ten year period. (See Figure 6.2.) At a 10% discount rate the total $670 million program has a present value of $425 million ($1975). With the assumption of increasing fuel prices as described above, the pay-out period is 12 years for this investment and "break-even" occurs in the year 1987. Using an alternative price inflation of 2% beginning in 1980 and a discount rate of 5% causes dollar benefits to increase to $11.5 billion ($1975) and the pay-out period remains the same. These benefit/cost streams imply a benefit/cost ratio of approximately 20:1. However, this ratio is only appropriate for the nation as a whole in terms of a fuel conservation hypothesis since industry expenditures for bringing the technology into commercial use have not been incorporated in the cost streams.

If, in 1985, 900,000 barrels/day of jet fuel were all that were available, would the demand for air travel exceed the supply?* The U.S. domestic fleet will require 530,000

* Project Independence Report, Federal Energy Administration, November 1974.

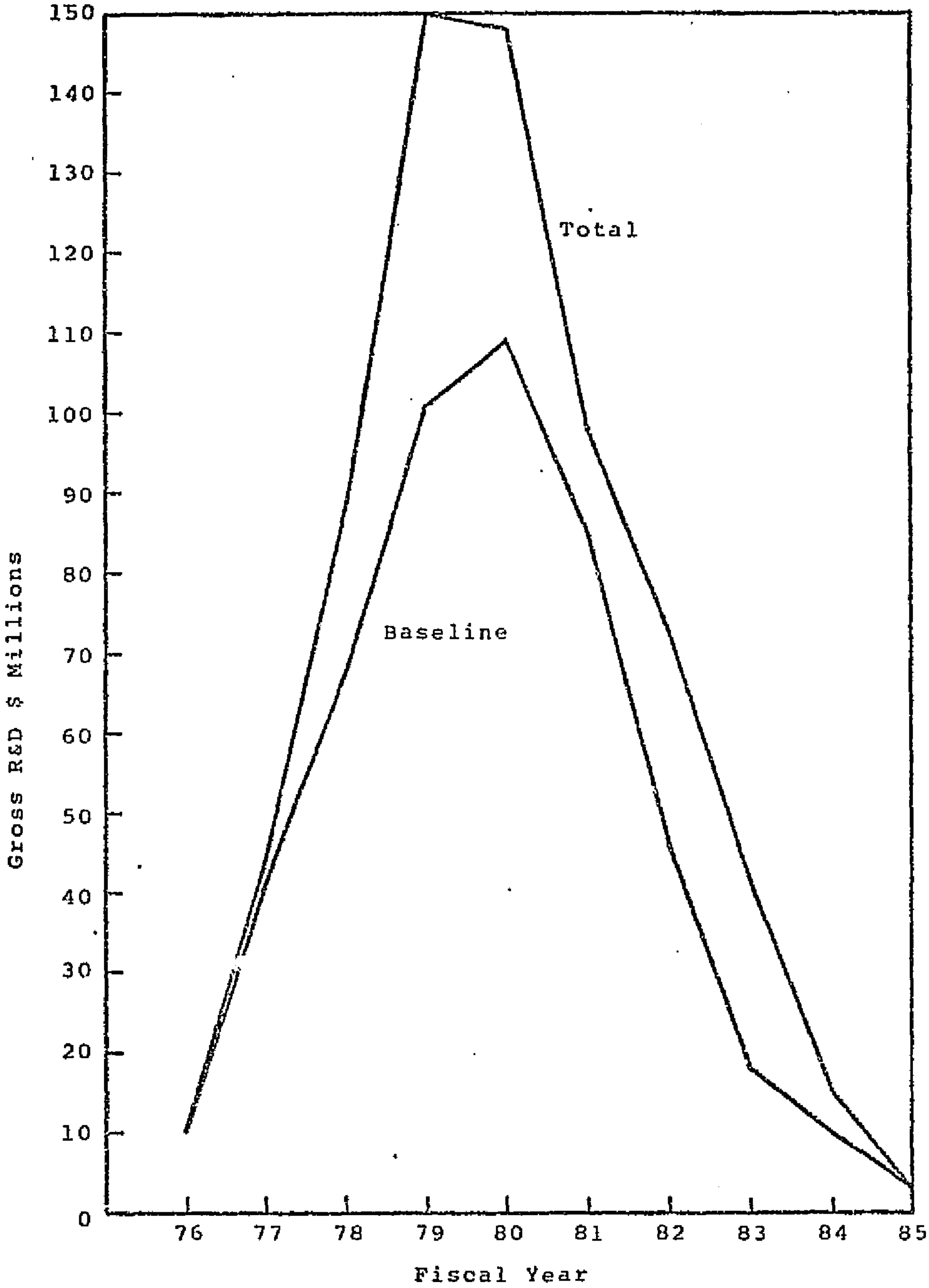


Figure 6.2 Total NASA Funding by Phases

barrels/day and the U.S. International fleet will require another 130,000 barrels/day. This leaves approximately 240,000 barrels/day to be spread among military, cargo, and other carriers. The NASA program would provide a savings of 39,000 barrels/day in the year 1985. The answer to the questions is that, without significant acceleration, the NASA program will not solve the problems now anticipated for 1985.

6.2 U.S. International Travel

The dollar and physical benefits shown above do not include benefits from U.S. International travel. Based on the assumption that U.S. International travel remains at 25% of domestic air travel, the benefits would be increased by more than $2.3 billion, for a total benefit of $11.7 billion. Reduced purchases of jet fuel of U.S. carriers in foreign ports will be approximately offset by decreased purchases of foreign-owned carriers in U.S. ports. Therefore, no additional balance of payments effects are realized.

6.3 The U.S. Balance of Payments Trade Flows

In 1973, aerospace exports were $5.2 billion and in 1974 were estimated at $7.0 billion,* which represents 7% of dollar exports (excluding military aid). Moreover, 65% of all orders for U.S. jet aircraft are foreign. This export strength is

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*Aerospace Industry Survey, Standard & Poor, October 31, 1974.

attributed to the "good buy" of American technology. If this position is to be maintained, the manufacturers cannot rely on favorable exchange rates (declining exchange value of the dollar) to make our technology competitive.

The development of technology incorporated into aircraft resulting in greater productivity is usually associated with higher initial capital costs. In this study, the assumption has been made that new fuel efficient technology, while lowering direct operating costs, would be offset** by increased capital costs of aircraft.

Using the further assumption that, for each aircraft sold to a U.S. carrier, one additional aircraft is also sold to a foreign carrier (see Section 3.4) U.S. engine and airframe manufacturers will show increased dollar exports (over the sale of an equivalent fleet of non-fuel-conservative aircraft) equivalent to the dollar amount of fuel saved. This results in a balance of payments benefit of around $9 billion ($1975). If only 50% of the potential savings are captured (i.e., manufacturer and buyer share equally in the benefits) then $4.5 billion ($1975) over the 20 year period 1985-2005 can be expected from increased exports. These benefits are excluded from the benefit streams in the above calculations of cost/benefit ratios as they result from dollar flows and not from fuel conservation.

**This is in terms of total expenditures on the fleet and not on a single aircraft basis.

7.0 RECOMMENDATIONS FOR CONTINUING ASSESSMENTS

From the previous discussion of aircraft replacement policies there is shown to be a continual process of planning of research, development, marketing and production of aircraft. The factors controlling the replacement rates tend, in the long run, to be the manufacturing industry's continuing ability to make existing aircraft obsolete, and the airline industry's ability to finance new aircraft.

To attain their objective of creating technological obsolescence, the manufacturers give attention to many elements:

- Present fleet composition
- Predicted future fleet and its composition by size
- Substitutes for air travel (car, bus and train economics)
- Future maintenance requirements
- Better aircraft performance and economics
- Financial health of the airlines.

Fuel consumption will be 20% to 35% of direct operating cost, depending on future fuel prices, and manufacturers will address all these elements to gain reduced maintenance costs, better utilization potential (through shorter turn-arounds or all-weather capabilities), and better space utilization (more seats or more cargo for a given aircraft size). In

considering these elements together, the most profitable price for aircraft may not embody the technology for minimum fuel consumption although, with recent price increases, fuel consumption is becoming a more important design-optimizing factor.

However, with the NASA fuel conservative aircraft program, industry will weight the fuel consumption element more heavily than if "business-as-usual" economics of aircraft manufacturing and purchasing prevailed. Since the lead time for incorporating the NASA R&D efforts is long, an ongoing assessment of benefits and costs should be pursued. The NASA program entails the planned expenditure of $670 million in a ten year period to develop the technology for fuel conservation in air transportation. In the course of this program it may be assumed that some of the technology investments will mature earlier or will be more successful in terms of performance objectives than others. Thus, it is important that NASA should develop short run (two or three year) criteria for decision making to enable the modification of the technology program to capitalize upon successful accomplishments. Neither the cost, schedule, nor the technical objectives of these programs are deterministic. Thus, the decision criteria should include the analysis of the cost and schedule risk of each program element as a function of technical objectives. This will serve to identify initial decision nodes in the development process,

as well as the trade-offs between technical objectives, and cost and schedule. NASA will then be in a position to select the technology mix which will yield the maximum fuel conservation impact for a given level of expenditure. The following relationships need to be determined.

- *Time-Cost development trade-offs*

  This is necessary for determining whether any of the technology programs can be accelerated.

- *Technology substitution trade-offs*

  This is necessary for incorporating accomplishments into a "combined system" for an attainable aircraft.

- *Airline economic trade-offs between on-hand aircraft and new orders for aircraft*

  This is necessary to judge whether with derivative and new generation aircraft the NASA supported technology can be economically incorporated into the airline fleet.

- *Industry expenditures for support of NASA fuel conservative aircraft program*

  This is necessary to judge the economic viability of incorporating the technology into production aircraft. Industry expenditures on the proposed technology have not been quantified in our analysis.

- *Capability-expenditure trade-offs*

  This is necessary to achieve the highest probability

of success for each technology area.

- *Aircraft production possibility trade-offs*
  This is necessary to judge employment impacts and materials requirements.

The ability to obtain and monitor the above six relationships will provide NASA with information inputs to control and manage the allocation of the $670 million in program funds among the engine and airframe manufacturers and their subcontractors.

The benefit estimates described in this report were produced in a brief but intensive effort. In order to produce these estimates it was necessary to make several simplifying assumptions concerning one of the major driving factors for the introduction of new aircraft; that is, the demand for air transportation. While the results obtained are probably sufficiently accurate for the purpose of evaluating the worth of the proposed program at this time, the assumptions should be subjected to further study. For example, in this analysis it was assumed that the demand for short, medium and long range air transportation would all increase at the same rate. If the growth rate of one of these three categories is significantly greater than the others, the mix of the technology to be developed to maximize fuel conservation could be modified. This study of demand should include:

- *Analysis of specific city pairs*

  The demand between specific city pairs should be studied to evaluate the expected travel volume for different stage lengths as well as the traffic growth rate. This "bottom-up" analysis can be used to predict more accurately future fleet requirements.

- *Comparing the cost of travel using alternative intermodal structures*

  This is necessary to evaluate the benefits accruing in the short range air travel market and for the assessment of the technology program directed towards short range aircraft.

- *Unbundling the growth assumptions*

  Fuel savings (benefits) are sensitive to the rate of growth. The effects of regulated load factors, the impact of charters and the substitutability of cargo capacity for passenger capacity need further investigation to evaluate their effect on the growth rate of air travel demand.

An important area of further study relates to the utilization of the NASA developed technology by the air transportation industry. With a free market, existing aircraft will be replaced by the airlines only when it is economically feasible and attractive to do so. Given a national objective

of fuel conservation, it may be desirable for the government to use incentives to encourage the replacement of older, less effective aircraft with fuel conservative aircraft at an earlier date than might otherwise occur. The nature of these incentives, their costs and their impact upon the benefits should be studied.